A PRELIMINARY ASSESSMENT OF THE HYDROLOGIC CHARACTERISTICS OF THE JAMES RIVER IN SOUTH DAKOTA

By Rick D. Benson

U.S. GEOLOGICAL SURVEY

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UNITED STATES DEPARTMENT OF THE INTERIOR

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For those readers who may prefer to use the International System of units rather than inch-pound units, the conversion factors for the terms used in this report are given below.

Multiply inch-pound unit	By	To obtain SI unit
inch	25.40	millimeter
foot per mile	0.18943	meter per kilometer
foot	0.3048	meter
foot per second	0.3048	meter per second
mile	1.609	kilometer
square mile	2.590	square kilometer
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
acre	0.4047	hectare
acre-foot	1,233	cubic meter
acre-foot per acre	3,047	cubic meter per hectare
gallon per minute	0.003785	cubic meter per second
micromhos per centimeter (µmho/cm)	1.00	microsiemen per centimeter (µS/cm)

To convert degrees Celsius (°C) to degrees Fahrenheit (°F) use the following formula: °F = 1.8 x °C + 32.

National Geodetic Vertical Datum of 1929 (NGVD of 1929): A geodetic datum derived from a general adjustment of the first-order nets of both the United States and Canada, formerly called mean sea level.

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ABSTRACT

This report, summarizing the results of a 6-month investigation of the hydrologic characteristics of the James River in South Dakota, was prepared at the request of the U.S. Bureau of Reclamation. Information provided in this report will be used by the Bureau as part of a joint study effort between the Bureau and the State of South Dakota in an ongoing investigation of the potential of supplying additional water from the Garrison Diversion Unit in North Dakota to the James River in South Dakota.

The James River in South Dakota has very restricted channel capacities in the upstream reach within the Lake Dakota Plain. Channel capacities in Brown County are as little as 200 cubic feet per second, and spring flooding can be expected on an average of every other year. The entire river in South Dakota has potential for extended periods of flooding an average of once in 10 years. Extended periods of no flow during late-summer and winter also can be expected. Excluding flows of a very large magnitude, average traveltime between Columbia and Scotland (a distance of 382 river miles) is estimated to be 25-30 days for most flows. The upstream reach of the James River within the Lake Dakota Plain generally loses discharge with distance whereas the downstream reach generally gains discharge with distance. Interaction between underlying aquifers and the river does not appear to be significant along upstream reaches of the James River. Some interaction, although not quantified, does occur in Hanson, Davison, and Yankton Counties.

Sand Lake National Wildlife Refuge, located just downstream from the State line and containing Sand and Mud Lakes (combined capacity = 24,600 acre-feet), is a major source of water loss between LaMoure, N. Dak., and Columbia, S. Dak. Gross evaporation losses from the lakes during 1969-81 are estimated to have been slightly more than 29,000 acre-feet per year. Unaccounted-for losses in the lake system are estimated to have been slightly more than 19,000 acre-feet per year. Water-quality analyses of lake samples indicated detectable concentrations of certain pesticides (2,4-D; DEF; atrazine; dicamba; and picloram). Dissolved-oxygen monitoring indicated probable photosynthetic activity in both lakes.

INTRODUCTION

Background

The U.S. Bureau of Reclamation and the State of South Dakota are jointly investigating the potential of supplying additional water from the Garrison Diversion Unit in North Dakota to the James River in South Dakota. The additional water supplies to South Dakota would be used along the entire James River area for municipal, industrial, irrigation, recreational and fish and wildlife purposes.

Investigations were begun by the establishment of a Garrison Study Management Board in May 1981 by the Governor of the State of South Dakota. At the request of the State and through the guidance of this Management Board, the Bureau completed a special report titled "Garrison Extension Special Report" in January 1982. It became apparent from this report that further appraisal investigations were needed and a joint study titled "South Dakota Water Deliveries Study" was begun between the Bureau and the State. As part of this ongoing investigation, the Bureau requested that the U.S. Geological Survey conduct certain hydrologic and hydraulic studies on the James River in South Dakota. These studies are summarized in this report.

Objectives and Scope

The objectives of this study were to more accurately define certain hydrologic and hydraulic characteristics of the James River and its tributaries in South Dakota, to analyze the water budget and water quality within the Sand Lake National Wildlife Refuge, and to identify the need for additional studies. Hydrologic and hydraulic characteristics are defined based on analyses of channel capacity, flow duration, flood-wave traveltimes and mean velocities, stream gains and losses, flood frequencies, and a review of ground-water/surface-water relationships. The majority of the study is based on currently available data (1981); however, some onsite work was done including discharge measurements, well location, and water-quality sampling.

Setting

The James River is a prairie stream that originates near Fessenden, N. Dak., and joins the Missouri River near Yankton, S. Dak. (fig. 1). The river is about 747 miles long, with about 273 river miles located in North Dakota and about 474 river miles located in South Dakota. The James River basin encompasses approximately 22,000 square miles, with about 14,000 square miles located in eastern South Dakota and about 8,000 square miles located in southeastern North Dakota.

The basin is located in the Central Lowlands physiographic province, occupying a relatively flat plain between the Coteau du Missouri on the west and the Coteau des Prairies on the east (Flint, 1955). Near the North Dakota-South Dakota border, the river enters an area of about 2,000 square miles called the Lake Dakota Plain (fig. 1). A majority of the soils in the basin were formed on glacial till or loamy glacial drift. Within the Lake Dakota Plain, soils were formed on sandy to clayey lake sediments.

The James River has one of the flattest slopes of any river of similar length in North America. In South Dakota, the altitude of the river only decreases about 130 feet in 474 river miles. Within the Lake Dakota Plain, the slope of the river in southern Brown County is less than 0.1 foot per mile.

Channel capacities within South Dakota vary between a minimum of 200 ft^3/s in southern Brown County to a maximum of 10,000 ft^3/s near the mouth. Frequent flooding occurs within the Lake Dakota Plain during spring snowmelt. Since 1940, the river within the Lake Dakota Plain has flooded in 1943, 1947, 1948, 1950, 1951, 1952, 1962, 1966, 1969, 1972, 1975, 1978, and 1982, or an average of every 3.3 years. Less frequent flooding also occurs during spring snowmelt on the lower James River downstream from Huron, S. Dak.

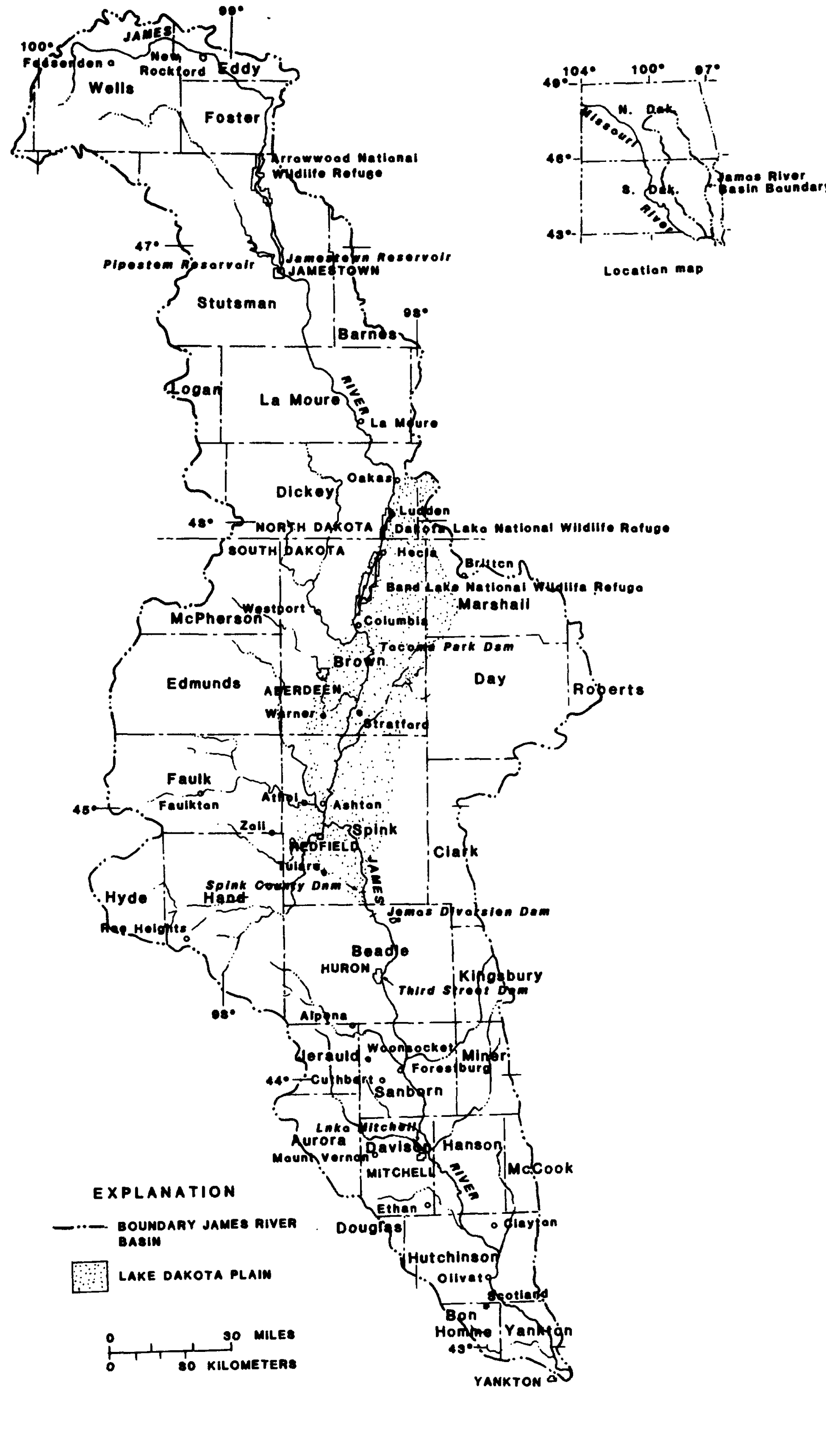


Figure 1.--James River basin.

Within the Lake Dakota Plain, high tributary inflows can cause the river to flow in the upstream direction (reverse flow) on certain occasions. In 1969, inflows from the Elm River caused the James to flow in the reverse direction at Columbia, S. Dak., for 9 days (maximum daily discharge equal to -1,860 ft^3/s) and inflows from Snake Creek caused the James to flow in the reverse direction at Ashton, S. Dak., for 7 days (maximum daily discharge equal to -2,100 ft^3/s).

Regulation of flows entering South Dakota is provided by Jamestown Reservoir, constructed by the Bureau of Reclamation, and Pipestem Reservoir, constructed by the U.S. Army Corps of Engineers, both located near Jamestown, N. Dak. Three major National Wildlife Refuges are located on the river between New Rockford, N. Dak., and Columbia, S. Dak.; they are: Arrowwood, Dakota Lake, and Sand Lake.

Two dams are located on the main stem near Huron. They are the James Diversion Dam (capacity 4,980 acre-feet) and the Third Street Dam (capacity 2,700 acre-feet) which both serve as the city of Huron's major water supply. Several other smaller dams are located on the main stem within South Dakota. Most of the smaller dams were privately constructed and are used as river crossings or as diversion points for private irrigation. Other dams (Tacoma Park and Spink County) serve primarily as recreation points on the river.

The Geological Survey has collected flow and water-quality data at several locations within the basin in South Dakota. Data collected at the main-stem gages are summarized in table 1 (the station at LaMoure, N. Dak., also is included in this table). Similar data for the tributaries are summarized in table 2 and locations where water-quality data have been collected are summarized in table 3. The location of the Geological Survey gaging stations (both active and discontinued) within the basin in South Dakota are shown in figure 2. Four stations, installed in 1981 for a 1-year sediment study in the lower James area, are not included in table 2 or in figure 2. Plots of historic streamflow for the main-stem gaging stations are included in the Supplemental Information section (figs. 30-37) at the back of the report.

Table 1.--Streamflow-gaging stations operated by the U.S. Geological Survey on the James River between LaMoure, N. Dak., and Scotland, S. Dak.

Station No.	Station name	Distance upstream from mouth (river miles)	Drainage area (square miles)		Discharge records			
						Discharge (cubic feet per second)		
			Total	Non-contrib-uting	Period of record	Minimum daily	Average	Maximum instantaneous
06470500	James River at LaMoure, N. Dak.	533	4,390	2,600	4/50-9/81	0	91.5	6,800
06470878	James River at North Dakota-South Dakota State line.	--	--	--	1/	--	--	--
06470980	James River at Hecla, S. Dak.	--	--	--	1/	--	--	--
06471000	James River at Columbia, S. Dak.	437	7,050	3,000	10/45-9/81	-1,860	107	5,420
06472000	James River near Stratford, S. Dak.	358	9,990	2/	3/50-9/72	0	130	5,580
06473000	James River at Ashton, S. Dak.	313	11,000	4,190	10/45-9/81	-2,100	156	5,680
06475000	James River near Redfield, S. Dak.	294	14,800	4,600	3/50-9/81	0	185	7,310
06476000	James River at Huron, S. Dak.	232	16,800	4,790	8/28-9/32 8/43-9/81	0	230	9,000
06477000	James River near Forestburg, S. Dak.	189	18,600	4,790	3/50-9/81	0	272	12,500
06478000	James River near Mitchell, S. Dak.	138	19,800	2/	7/53-9/58 8/65-9/72	1.0	313	13,800
06478500	James River near Scotland, S. Dak.	55	21,550	4,790	9/28-9/81	0	368	15,200
06478513	James River near Yankton, S. Dak.	--	--	--	1/	--	--	--

1/ Gaging stations established in 1981.
2/ Determination of non-contributing drainage area has not been made.

Table 2.--Streamflow-gaging stations operated by the U.S. Geological Survey on tributaries within the James River basin in South Dakota

Station No.	Station name	Distance upstream from mouth (river miles)	Drainage area (square miles): Total	Drainage area (square miles): Non-contributing	Discharge records: Period of record	Discharge (cubic feet per second): Minimum daily	Discharge (cubic feet per second): Average	Discharge (cubic feet per second): Maximum instantaneous
06471200	Maple River at North Dakota-South Dakota State line.	15.7	750	270	6/56-9/81	0	19.3	5,930
06471500	Elm River at Westport, S. Dak.	30.4	1,680	510	10/45-9/81	0	45.8	12,600
06471898	Moccasin Creek near Warner, S. Dak.	21.5	256	1/	10/76-9/80	0	2/	387
06472500	Mud Creek near Stratford, S. Dak.	14.7	730	270	9/55-9/69	0	10.0	1,180
06473500	South Fork Snake Creek near Athol, S. Dak.	3/	1,820	730	3/50-9/72	0	11.2	6,810
06473700	Snake Creek near Ashton, S. Dak.	21.5	2,620	850	10/55-9/69 10/76-9/79	0	23.8	6,980
06473750	Wolf Creek near Ree Heights, S. Dak.	3/	265	1/	9/59-9/81	0	3.73	990
06474000	Turtle Creek near Tulare, S. Dak.	33.7	1,120	1/	8/53-9/56 9/65-9/81	0	13.0	6,000
06474300	Medicine Creek near Zell, S. Dak.	3/	210	1/	9/59-9/81	0	5.72	2,210
06474500	Turtle Creek at Redfield, S. Dak.	6.8	1,540	1/	10/45-9/72	0	24.8	7,660
06476500	Sand Creek near Alpena, S. Dak.	40.7	240	1/	3/50-9/81	0	8.58	2,240
06477150	Rock Creek near Fulton, S. Dak.	9.5	270	1/	10/66-9/72	0	9.01	2,040

Table 2.--Streamflow-gaging stations operated by the U.S. Geological Survey on tributaries within the James River basin in South Dakota--Continued

Station No.	Station name	Distance upstream from mouth (river miles)	Drainage area (square miles)		Discharge records			
			Total	Non-contributing	Period of record	Discharge (cubic feet per second) Minimum daily	Average	Maximum instantaneous
06477500	Firesteel Creek near Mount Vernon, S. Dak.	30.2	540	1/	9/55-9/81	0	20.1	6,610
06478052	Enemy Creek near Mitchell, S. Dak.	7.3	181	1/	10/75-9/81	0	2.91	1,390
06478390	Wolf Creek near Clayton, S. Dak.	4.1	386	1/	10/75-9/81	0	18.2	1,280

1/ Determination of non-contributing drainage area has not been made.
2/ Average discharge for period of record has not been computed.
3/ Tributaries do not discharge directly to the James River.

Table 3.--Water-quality sampling stations operated by the U.S. Geological Survey on the James River between LaMoure, N. Dak., and Scotland, S. Dak.

Station No.	Station name	Period of daily record		Period of record for monthly samples[1]
		Temperature	Specific conductance	
06470500	James River at LaMoure, N. Dak.	6/53-9/75 10/76-9/81	10/76-9/81	10/56-9/81
06470878	James River at North Dakota-South Dakota State line.	10/74-9/81	10/74-9/81	10/53-9/81
06471000	James River at Columbia, S. Dak.	10/66-9/78	10/66-9/79	10/48-9/64 10/66-9/81
06473000	James River at Ashton, S. Dak.	10/77-9/81	--	10/77-9/78
06475000	James River near Redfield, S. Dak.	10/77-9/80	--	--
06476000	James River at Huron, S. Dak.	9/56-10/70 9/71-9/81	9/56-10/70 9/71-9/81	10/48-9/52 10/55-9/81
06478500	James River near Scotland, S. Dak.	1/53-9/69 10/74-9/81	10/74-9/81	10/55-9/64 10/66-9/73 9/74-9/81

1/ Degree of detail for analyses varies, but usually includes major anions and cations.

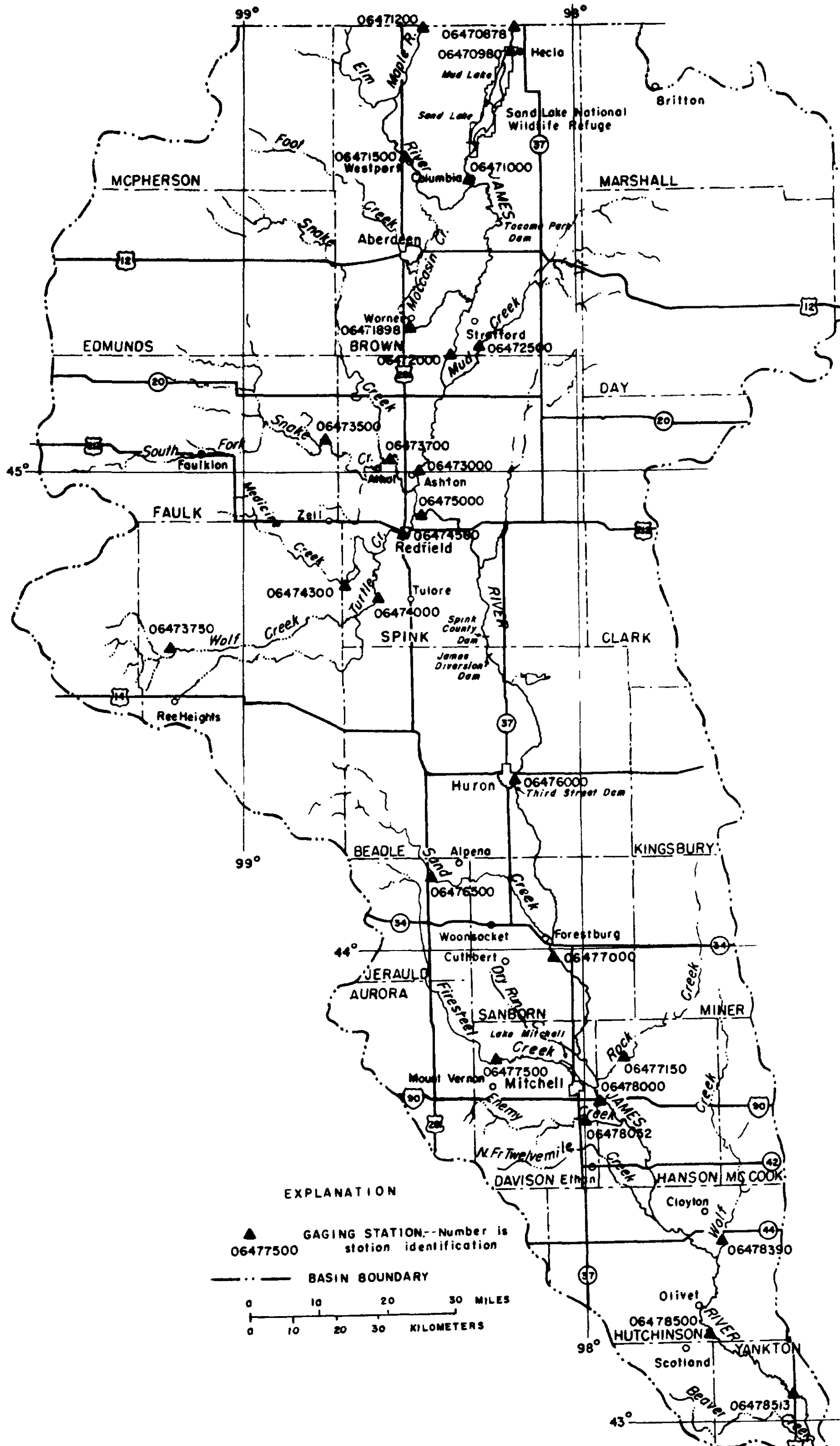


Figure 2.--Streamflow gaging stations operated by the U.S. Geological Survey within the James River basin in South Dakota.

ANALYSIS OF CHANNEL CAPACITY

Procedure

An attempt was made to define bankfull capacities by making discharge measurements when the James River was at or near bankfull capacity. Discharge measurements were made at 23 sites on the river in South Dakota (fig. 3).

The initial measurements were made April 26-28, 1982, when the river was at or near bankfull capacity in the reach between the Brown-Spink County line and Huron. The river did not reach bankfull capacity downstream from Huron and the discharge measurements in that reach were made May 3-6, 1982. The final measurements were made June 16-18, 1982, when the river in the reach within Brown County had receeded to near bankfull capacity.

Discussion

The discharge measurements, summarized in table 4, accurately reflect the channel characteristics of the James River in South Dakota. Within Brown County (sites 1-6), discharges of between 156 and 386 ft^3/s caused bankfull conditions at most locations. Between the Brown-Spink County line and the vicinity of Ashton (sites 7-10), discharges of between 799 and 1,060 ft^3/s caused bankfull conditions. South of the vicinity of Redfield (sites 11-23), bankfull conditions were not reached.

The restricted channel conditions present in Brown County are quite evident, as is the noted increase in channel capacity when the river leaves the Lake Dakota Plain near Redfield.

Estimated bankfull capacities for the James River at selected locations in South Dakota are summarized in table 5. The Geological Survey estimates are based on the discharge measurements contained in table 4. The other estimates have been reported by the U.S. Bureau of Reclamation (1977, table 1) and the Missouri River Basin Commission (1980a, p. 9, p. 13).

ANALYSIS OF FLOW DURATION

Procedure

Duration hydrograph plots were prepared for each of the main-stem gaging stations, using Program K956 (Wilson, 1981) in conjunction with mean daily-discharge data stored in the U.S. Geological Survey's WATSTORE daily-values file. Each plot shows the daily discharge values for the 20-, 50-, and 80-percent exceedance values. A 20-percent exceedance value represents a mean daily discharge that can be expected to be equaled or exceeded on an individual day an average of once in 5 years (sometimes referred to as a 5-year flow). Likewise, the 80-percent value represents a mean daily discharge which can be expected to be equaled or exceeded on an individual day an average of once in 1.25 years (a 1.25-year flow). The 50-percent value (also the median in this particular application) can be expected to be equaled or exceeded on an individual day an average of once in 2 years (a 2-year flow). The minimum and maximum recorded daily values also are plotted.

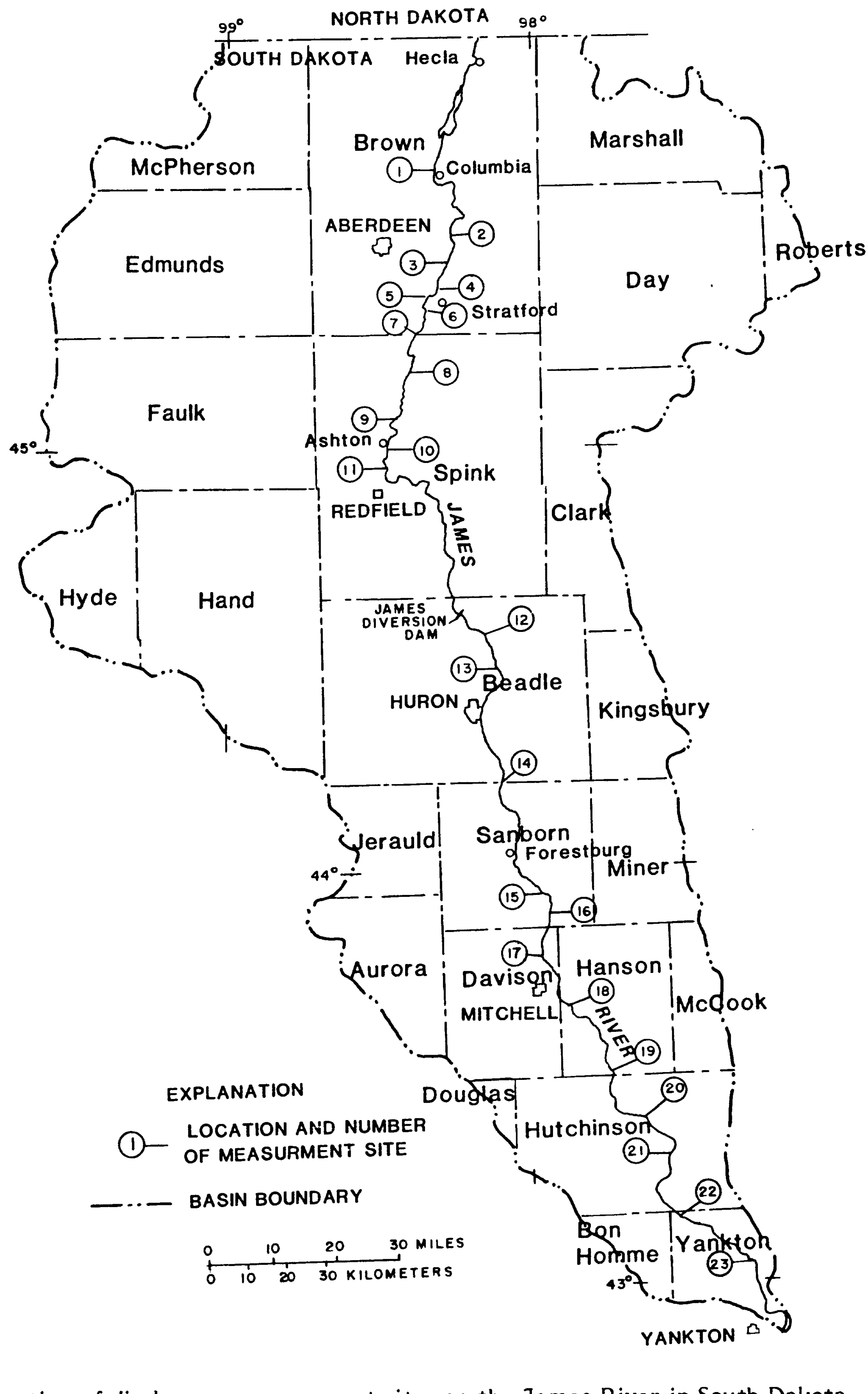


Figure 3.--Location of discharge-measurement sites on the James River in South Dakota.

Table 4.--Summary of discharge measurements for the James River, 1982

Site No.	Legal description	Date of measurement	Discharge (cubic feet per second)	Velocity (feet per second)	Remarks
1	sec.29, T.125N., R.62W.	6-17-82	156	0.66	Bankfull.
2	sec.11, T.123N., R.62W.	6-17-82	193	.31	4 feet below bankfull.
3	sec.10, T.122N., R.62W.	6-16-82	227	.27	2 feet below bankfull.
4	sec.28, T.122N., R.62W.	6-16-82	268	.40	Bankfull.
5	sec.31, T.122N., R.62W.	6-16-82	386	.29	Do.
6	sec.12, T.121N., R.63W.	6-18-82	280	.77	Do.
7	sec.3, T.120N., R.63W.	4-28-82	1,060	.84	Do.
8	sec.3, T.119N., R.63W.	4-28-82	1,020	1.20	Do.
9	sec.18, T.118N., R.63W.	4-27-82	908	1.37	Do.
10	sec.12, T.117N., R.64W.	4-27-82	799	1.24	Do.
11	sec.25, T.117N., R.64W.	4-27-82	933	1.80	6-8 feet below bankfull.
12	sec.5, T.112N., R.61W.	4-26-82	835	.38	2-3 feet below bankfull.
13	sec.2, T.111N., R.61W.	4-26-82	923	.65	3-4 feet below bankfull.
14	sec.10, T.108N., R.61W.	5- 3-82	944	1.56	2-3 feet below bankfull.
15	sec.34, T.106N., R.60W.	5- 4-82	903	.98	5-6 feet below bankfull.
16	sec.24, T.105N., R.60W.	5- 4-82	879	.90	9-10 feet below bankfull.
17	sec.22, T.104N., R.60W.	5- 4-82	983	1.20	2-3 feet below bankfull.
18	sec.9, T.102N., R.59W.	5- 4-82	895	.95	11-12 feet below bankfull.
19	sec.33, T.101N., R.58W.	5- 5-82	867	1.06	6-7 feet below bankfull.
20	sec.16, T.99N., R.58W.	5- 5-82	900	1.13	8-9 feet below bankfull.
21	sec.19, T.98N., R.57W.	5- 5-82	891	1.29	16-17 feet below bankfull.
22	sec.10, T.96N., R.57W.	5- 6-82	909	1.35	3-4 feet below bankfull.
23	sec.12, T.95N., R.56W.	5- 6-82	868	1.36	8-9 feet below bankfull

Table 5.—Representative channel capacities for the James River in South Dakota as determined by the U.S. Geological Survey, U.S. Bureau of Reclamation, and the Missouri River Basin Commission

Location	Representative channel capacity (cubic feet per second)		
	U.S. Geological Survey	U.S. Bureau of Reclamation	Missouri River Basin Commission
Columbia Road Dam			
	150-200	200	200
Columbia gaging station			
	—	700	700
Tacoma Park			
	—	350-500	425
U.S. Highway 12			
	200-300	200-300	300
Moccasin Creek			
	300-400	400	400
Stratford gaging station			
	1,000-1,100	1,000	500
Mud Creek			
	1,000-1,100	1,000	--
State Highway 20			
	--	1,000	1,000
Ashton gaging station			
	—	1,700	1,700
Snake Creek			
	—	3,000	3,000
Turtle Creek			
	—	5,000	--
Redfield gaging station			
	—	—	1/
James Diversion Dam			
	—	—	3,800
Huron gaging station			
	—	—	2,700
Beadle/Sanborn County line			
	—	—	3,000
Forestburg gaging station			
	—	—	3,400
State Highway 37			
	—	—	1,000
Mitchell			
	—	—	2,000
State Highway 42			
	—	—	2,600
State Highway 44			
	—	—	3,400
Olivet			
	—	—	2,800
Scotland gaging station			
	—	—	2,600
U.S. Highway 81			
	—	—	2,400
Mission Hill			
	—	—	10,000
Mouth			

1/ Backwater from James Diversion Dam.

Discussion

Following is a discussion of the duration hydrographs for each of the main-stem gages in South Dakota. Limitations in the computer program required that the analyses be made for 9, 19, 29, 39, or 49 years and, therefore, it was not possible to use the entire period of record for the analyses. The period of record on which each duration hydrograph is based is specified.

James River at Columbia

The duration hydrograph for the James River at Columbia (station 06471000) is shown in figure 4. The hydrograph is based on the 29 years of record from water year 1953 through water year 1981.

The hydrograph indicates that, during the 29 years, flows at Columbia never exceeded 200 ft^3/s during December 19-March 21. Twenty percent of the time, flows can be expected to exceed 200 ft^3/s on any individual day during April 10-August 1 (excluding June 4-10), or 124 days. The bankfull capacity of the river between Columbia and Stratford is as little as 200 ft^3/s at certain locations (table 5).

Fifty percent of the time, zero flow can be expected on any individual day during December 23-March 11 and September 12-October 15. Zero flow occurred on each day of the year sometime during the 29 years.

James River near Stratford

The duration hydrograph for the James River near Stratford (station 06472000) is shown in figure 5. The hydrograph is based on the 19 years of record from water year 1953 through water year 1971.

The hydrograph is quite similar to the one for Columbia discussed previously. Flows never exceeded 200 ft^3/s during December 28-March 19. Flows exceeding 200 ft^3/s can be expected in 1 of 5 years on any individual day during March 24-August 17. Daily flow with a 50-percent exceedance probability (equivalent to the median flow) during the first 25 days of May ranges between 196 and 228 ft^3/s. Considering the restricted channel capacity in the reach between Columbia and Stratford (200 ft^3/s), this indicates that bankful conditions or minor flooding can be expected every other year during May.

The hydrograph also indicates that, on an average of every other year, zero flow can be expected on any individual day during October 6-November 15 and January 5-March 7. As at Columbia, zero flow occurred on each day of the year sometime during the analysis period.

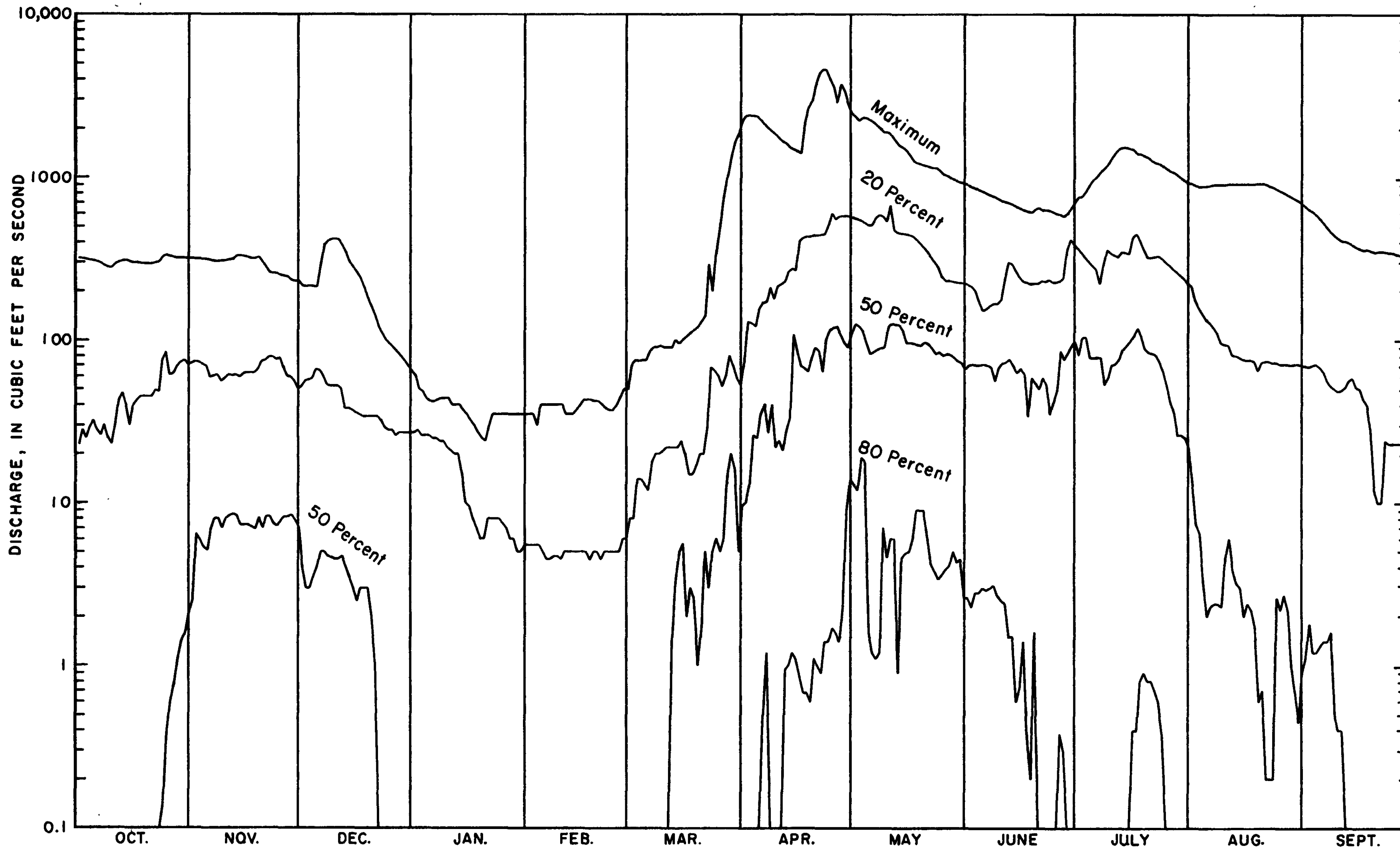


Figure 4.--Duration hydrograph for the James River at Columbia, S. Dak., water years 1953-81.

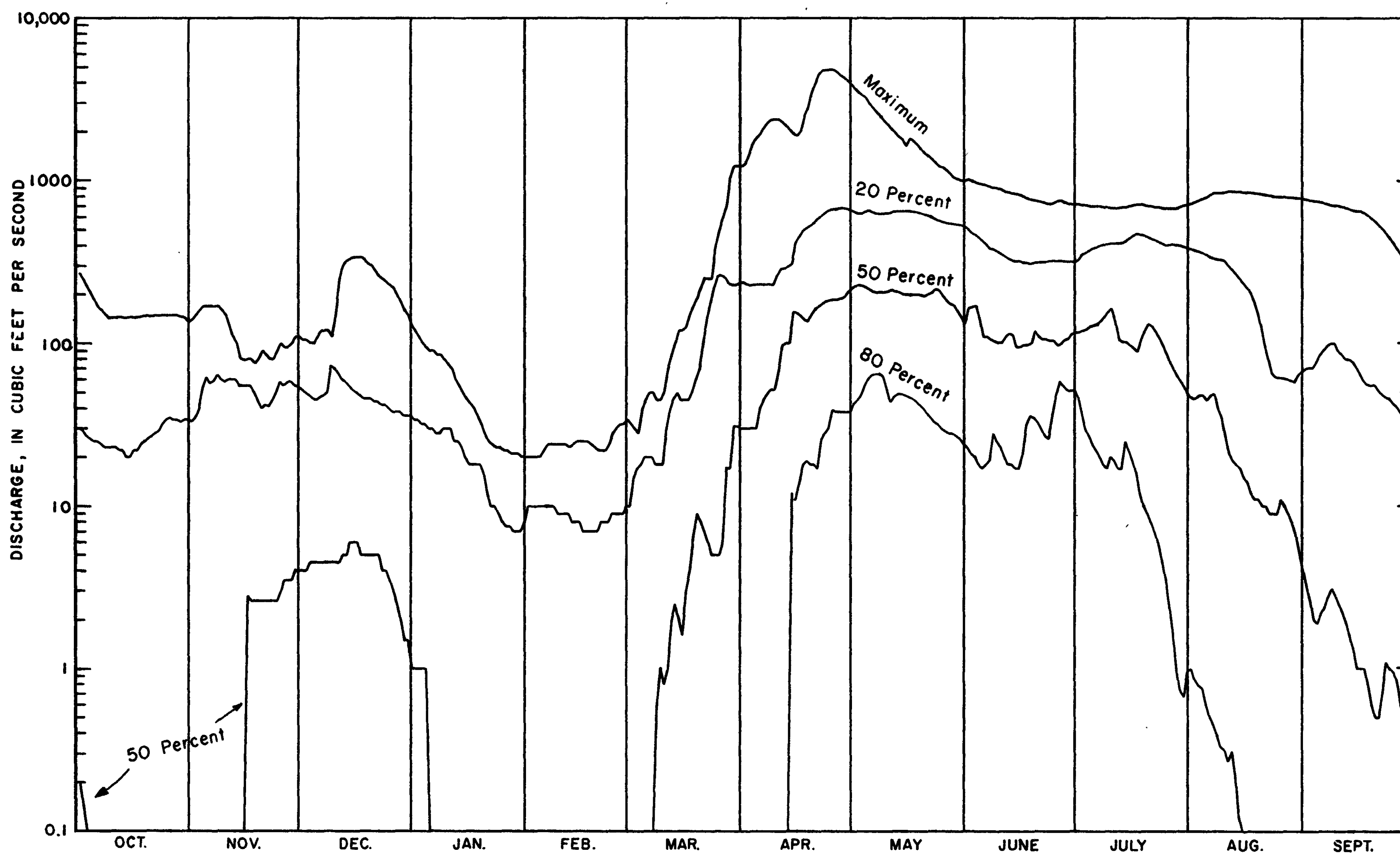


Figure 5.--Duration hydrograph for the James River near Stratford, S. Dak., water years 1953-71.

James River at Ashton

The duration hydrograph for the James River at Ashton (station 06473000) is presented in figure 6. The hydrograph is based on the 29 years of record from water year 1953 through water year 1981.

The channel capacity between Stratford and Ashton is estimated to be about 1,000 ft^3/s (see table 5). The data in figure 6 indicate that flows exceeding 1,000 ft^3/s have occurred during April 1-June 12 and July 18-August 21. However, the 20-percent exceedance flows at Ashton never exceed 1,000 ft^3/s. The duration-hydrograph tables (not included in this report) indicate that 10-percent exceedance flows (flows expected an average of once in 10 years) exceed 1,000 ft^3/s on any individual day during April 14-May 16, or 33 days.

The 50-percent exceedance flows (median flows) are zero during most of October and a part of November. As with the previous two stations, zero flow occurred on each day of the year sometime during the analysis period.

James River near Redfield

The duration hydrograph for the James River near Redfield (station 06475000) is presented in figure 7. The hydrograph is based on the 29 years of record from water year 1953 through water year 1981.

The channel capacity between Ashton and Redfield is estimated to be about 1,700 ft^3/s (table 5). Flows exceeding this have occurred during March 17-May 26. The 20-percent exceedance flows have not exceeded 1,700 ft^3/s. However, the 10-percent exceedance flows (not plotted) exceed 1,700 ft^3/s on any individual day during April 4-April 24. Therefore, flows exceeding bankfull capacity can be expected to occur on any given day during the 21 days in April an average of once every 10 years.

The median flow (50-percent exceedance) has always been greater than zero at Redfield, although it is less than 1 ft^3/s for 49 days during the year. Zero flow was not recorded at Redfield during April 5-May 13, May 17-19, and May 23-24. However, the flows were less than 3 ft^3/s during these periods.

James River at Huron

The duration hydrograph for the James River at Huron (station 06476000) is shown in figure 8. The hydrograph is based on the 29 years of record from water year 1953 through water year 1981.

The channel capacity between the James Diversion Dam and Huron is estimated to be about 3,800 ft^3/s (table 5). The data in figure 8 indicate that mean daily flows exceeding this value have occurred at Huron during March 27-May 12. The 10-percent exceedance flows (not plotted) equal or exceed 3,800 ft^3/s on individual days during March 31-April 7.

The 50-percent exceedance flow is 1 ft^3/s or less for 52 days, occurring during September through December. Unlike Redfield, zero flow was recorded on each day of the year sometime during the analysis period. This probably can be attributed to regulation by the James Diversion Dam, withdrawals for irrigation, and municipal withdrawals by the city of Huron.

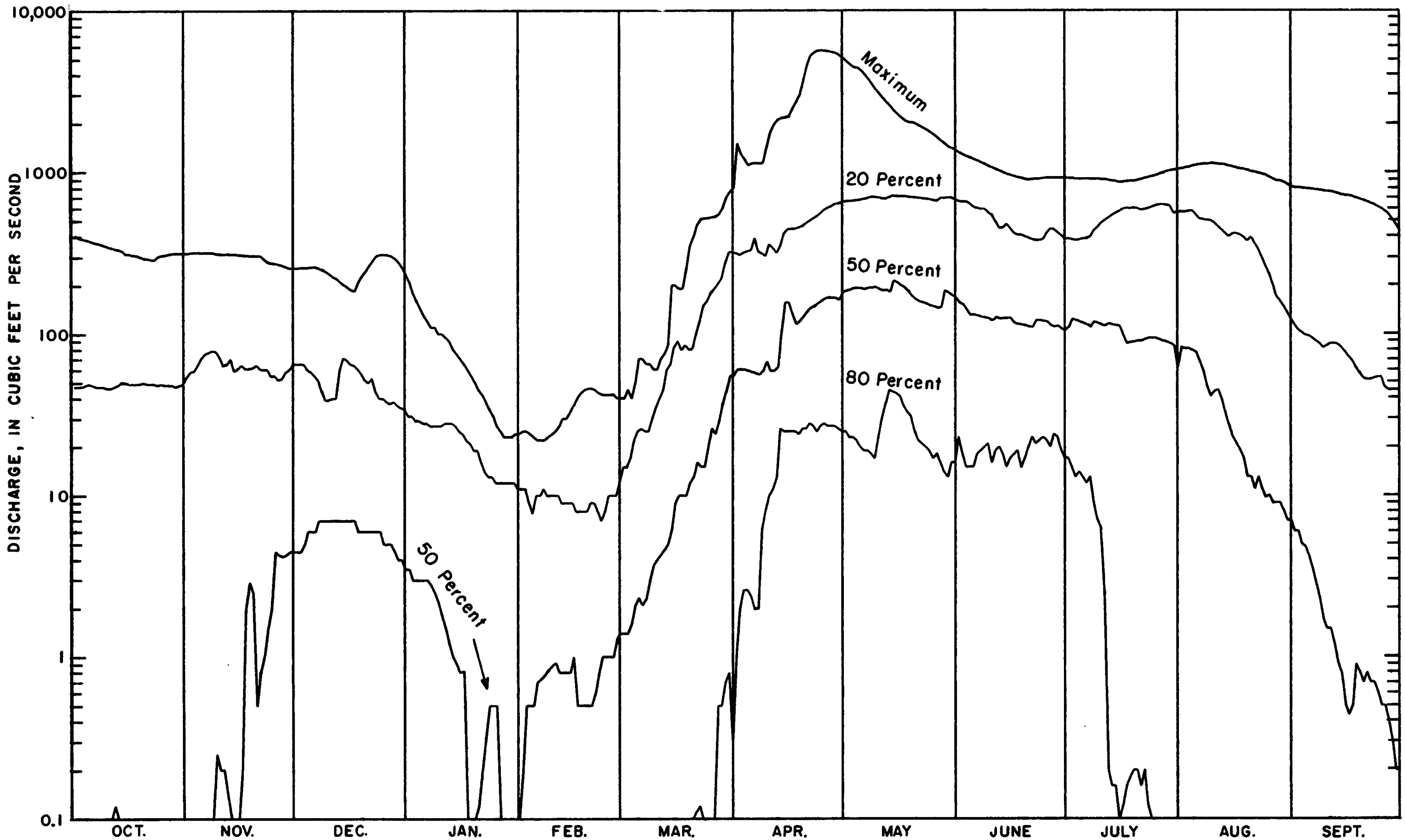


Figure 6.--Duration hydrograph for the James River at Ashton, S. Dak., water years 1953-81.

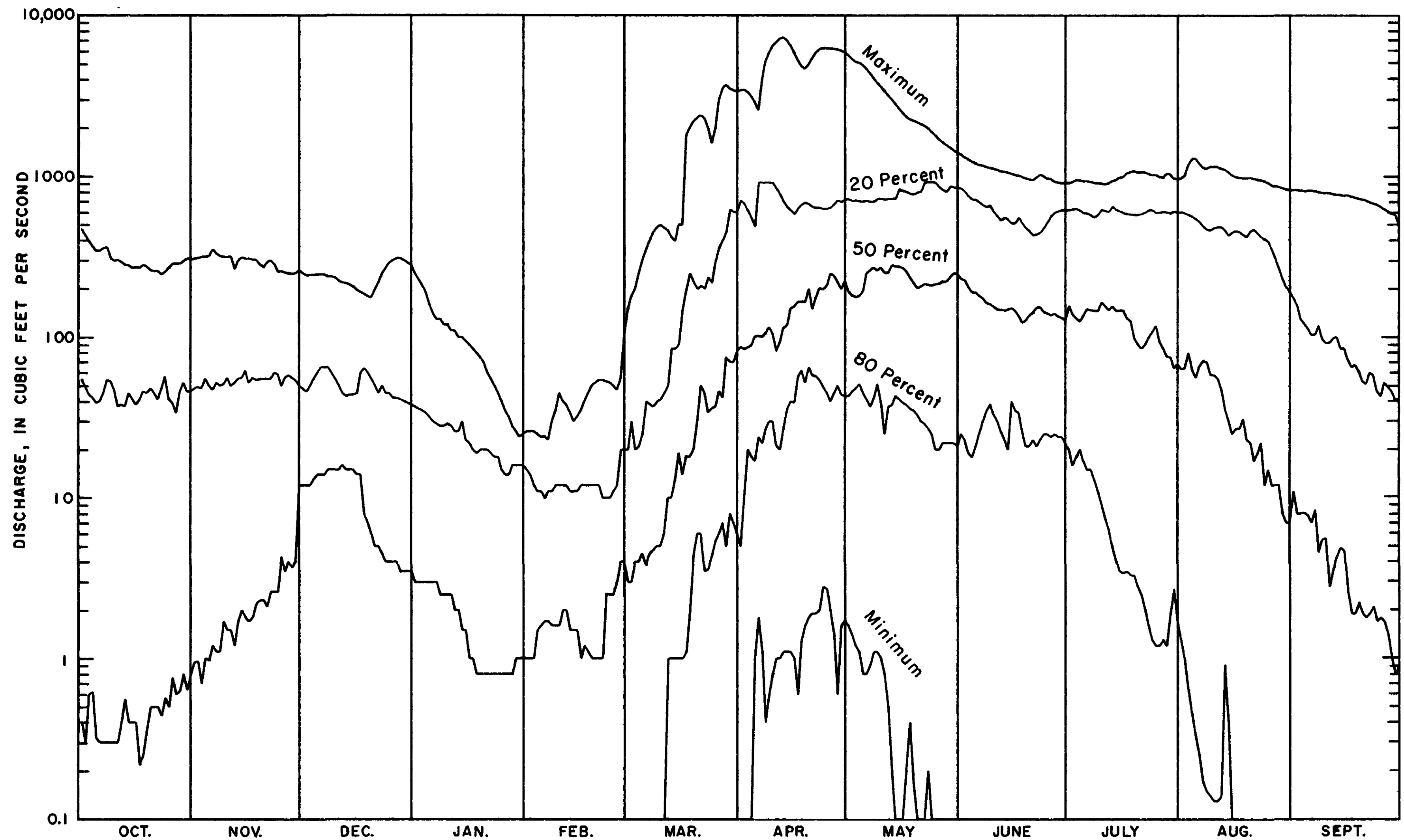


Figure 7.--Duration hydrograph for the James River near Redfield, S. Dak., water years 1953-81.

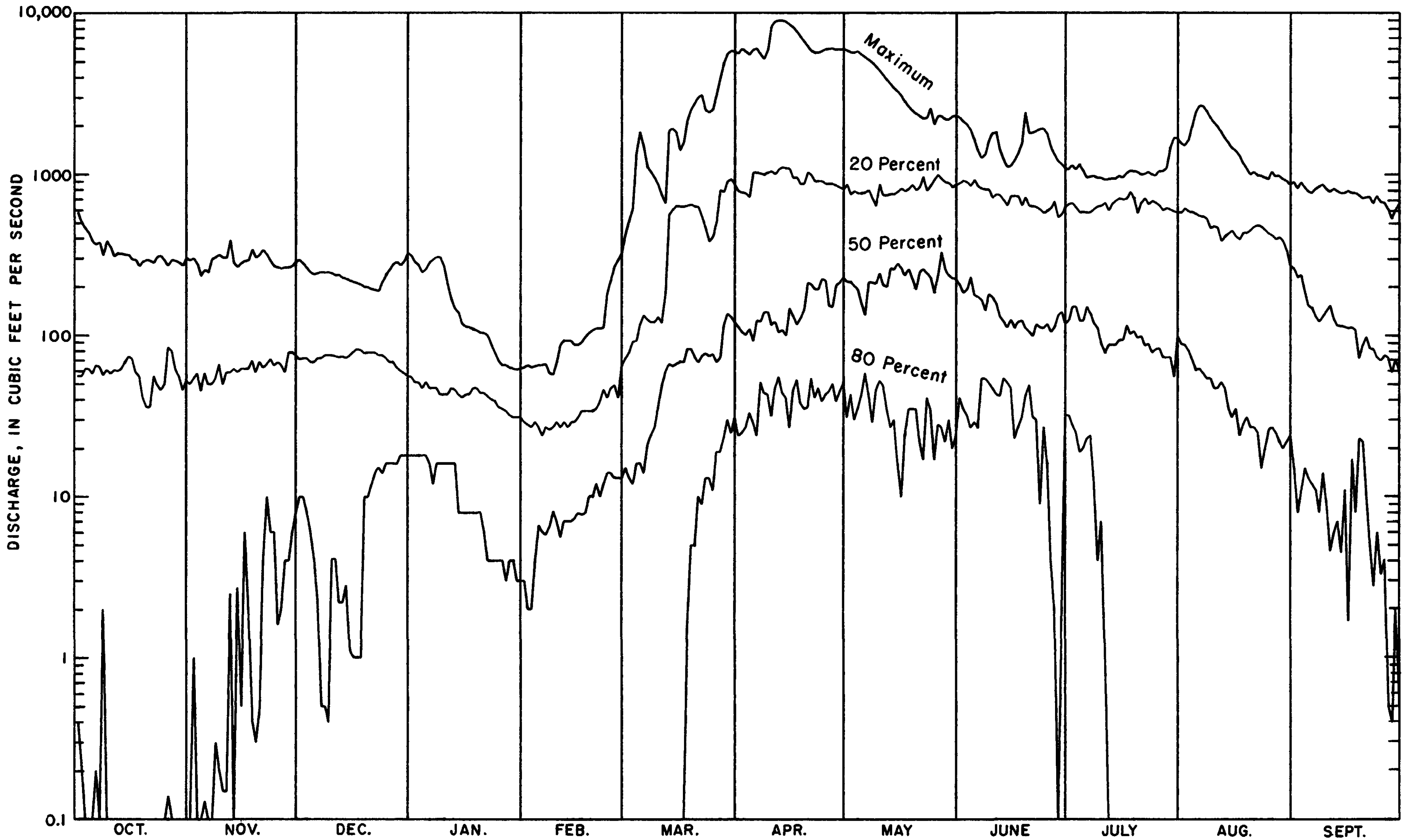


Figure 8.--Duration hydrograph for the James River at Huron, S. Dak., water years 1953-81.

James River near Forestburg

The duration hydrograph for the James River near Forestburg (station 06477000) is shown in figure 9. The hydrograph is based on the 29 years of record from water year 1953 through water year 1981.

The channel capacity between Huron and Forestburg is estimated to range between 2,700 and 3,000 ft^3/s (table 5). Flows exceeding 3,000 ft^3/s have been recorded on individual days during March 15-18, March 27-June 3, and June 10-16. The 10-percent exceedance flow (not plotted) exceeds 3,000 ft^3/s on individual days during March 31-April 14. The 50-percent exceedance flow (median) ranges between 6 ft^3/s (October 6) and 350 ft^3/s (May 15). Zero flow never was recorded during March 11-June 30 (minimum flows during June were 1 ft^3/s or less and are not plotted due to scale selection), although the highest minimum flow during this period was only 9 ft^3/s.

James River near Scotland

The duration hydrograph for the James River near Scotland (station 06478500) is presented in figure 10. The hydrograph is based on the 49 years of record from water year 1933 through water year 1981.

The channel capacity between Forestburg and Scotland is estimated to range between 1,000 and 3,400 ft^3/s (table 5). Flows exceeding 3,400 ft^3/s have been recorded on individual days during March 15-17 and March 20-July 22. Mean daily flows exceeding 1,000 ft^3/s have been recorded during February 13-21, February 25-August 17, August 30-September 1, September 3-5, September 22-25, and September 30. The 3,400-ft^3/s discharge is not exceeded by the 20-percent exceedance line, but is exceeded by the 10-percent line (not shown) on individual days during March 29-April 23. Thus, flows exceeding 3,400 ft^3/s can be expected an average of once in 10 years on any individual day during the 26 days from March 29 through April 23. A 1,000-ft^3/s mean daily flow is exceeded an average of once in 5 years on any given day during the 105 days from March 15-June 27and an average of once in 10 years on any given day during the 129 days from March 11-July 17. The 10-percent exceedance line also equals or exceeds 1,000 ft^3/s on individual days during March 6-8, July 22-25, and August 3-8.

The median flow (50-percent exceedance) ranges between 20 and 488 ft^3/s. Although not shown due to scale selection, zero flow at Scotland was recorded during January 30-February 4, July 12-September 1, and September 5-December 4 sometime during the analysis period.

Conclusions

The duration-hydrograph analysis of the main-stem gaging stations depicts the James River as a river with potential for relatively high flows during spring snowmelt and early-summer from thunderstorms and extended periods of no flow during late-summer to spring breakup. Upstream from Huron, zero flow conditions have occurred for an entire year.

When channel capacities are taken into consideration, the entire river in South Dakota has potential for extended periods of flooding an average of once in 10 years. Within the Lake Dakota Plain, especially Brown County, the river causes extended periods of spring flooding an average of once in 5 years. In the vicinity of Stratford, the restricted channel capacity results in flooding an average of every other year.

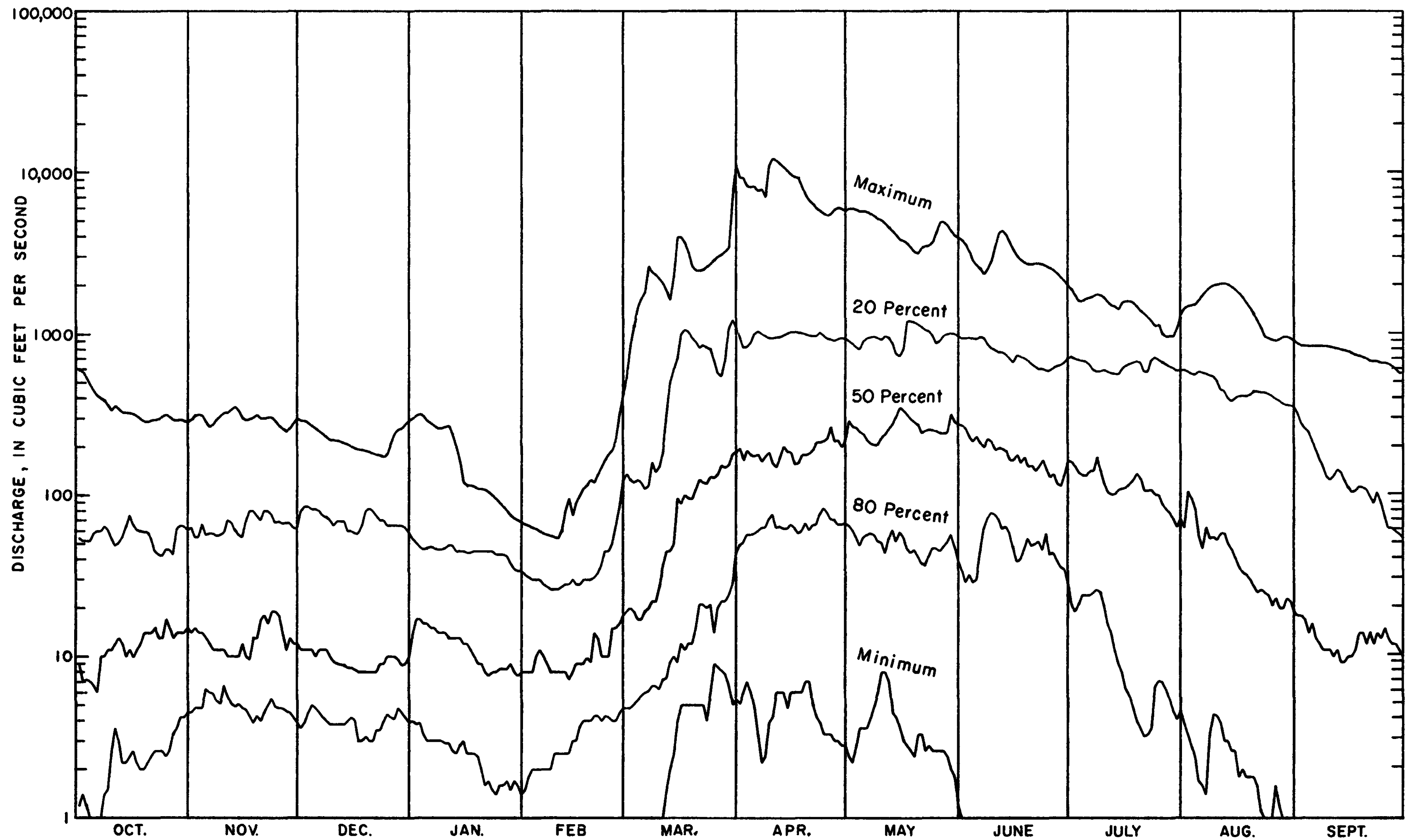


Figure 9.--Duration hydrograph for the James River near Forestburg, S. Dak., water years 1953-81.

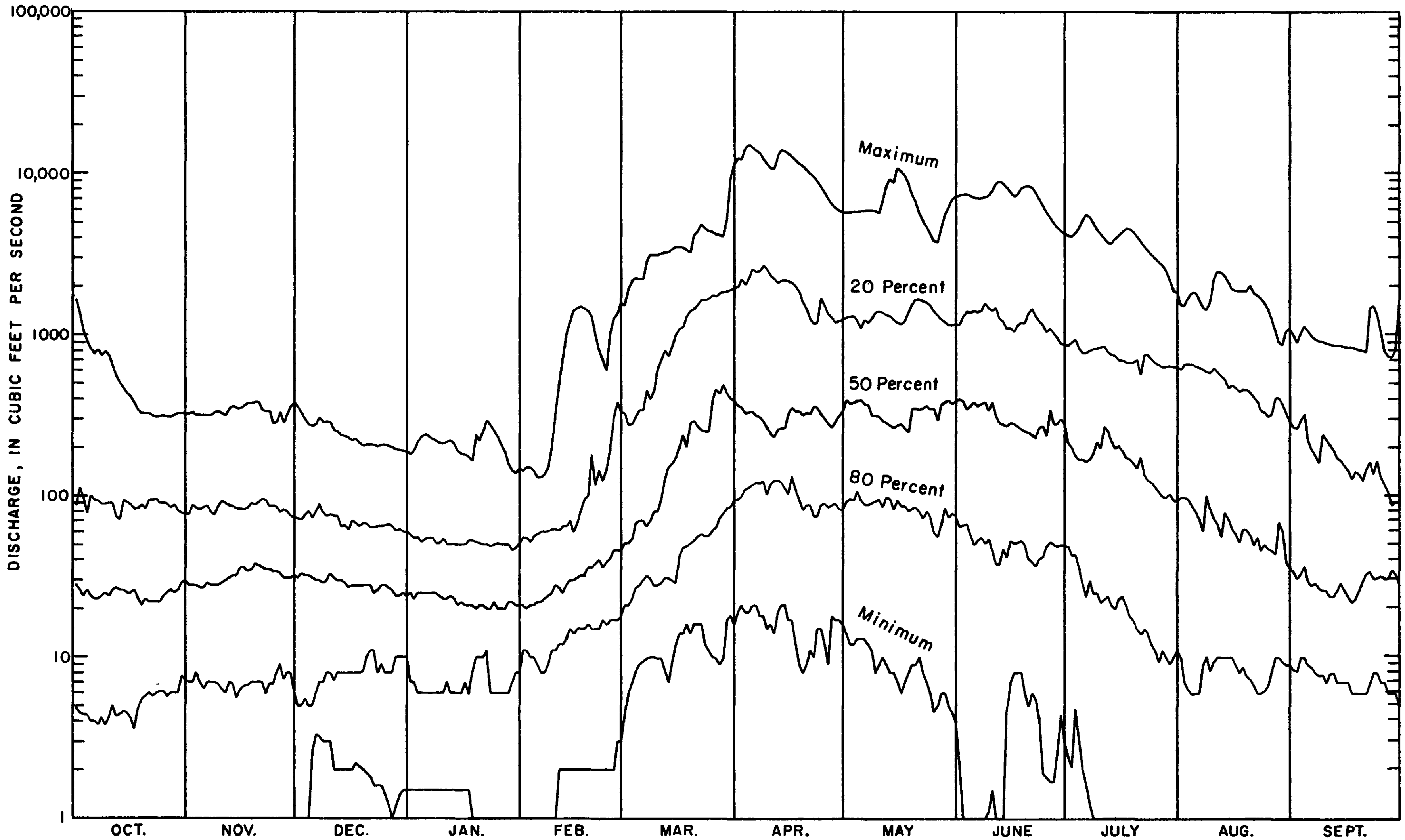


Figure 10.--Duration hydrograph for the James River near Scotland, S. Dak., water years 1933-81.

The duration-hydrograph analysis, in conjunction with the estimated channel capacities, should provide a tool to evaluate the potential flooding impacts of importation of additional flows into the James River in South Dakota. For instance, the importation of a certain volume of flow into the river virtually decreases the river's capability to convey natural flows by a volume equal to the imported flow. Therefore, the duration of flooding subsequent to flow importation can be analyzed by subtracting the imported flow from the bankfull capacity and then comparing this to the applicable duration hydrograph.

For example, importation of 100 ft^3/s of flow would decrease the river's capability to convey natural flows by 100 ft^3/s. In the vicinity of Stratford where the channel capacity is as little as 200 ft^3/s, the river's capability to convey natural flows would be decreased to 100 ft^3/s. From figure 5, the time span for the occurrence of the 5-year flow (20-percent exceedance probability) would be increased from 147 days (March 24-August 17) to 154 days (March 21-August 21). The impact on the median flow (50-percent exceedance probability) would be much greater where the time span for the occurrence of flows of 200 ft^3/s or more would be increased from 23 days to 94 days. Similar comparisons can be made for other imported flow volumes and at other locations.

ANALYSIS OF TRAVELTIME

Flood-Wave Velocity

Procedure

Daily-discharge values during water year 1969 through water year 1981 were retrieved from WATSTORE and plotted for each main-stem gaging station between Columbia and Scotland. The plots for each station were then compared to determine the number of days required for a specific flood-wave to travel through the river system. Flood-wave speed is called celerity and usually is 1.0 to 1.3 times faster than mean velocity.

It was necessary to give particular attention to the peaks caused by tributary inflows. During the snowmelt period, direct drainage and tributary inflows generally cause intermediate peaks which precede, and usually exceed, the peak of the flow traveling down the main stem. This is particularly true for a station such as the James River near Redfield where Turtle Creek, a major tributary, enters a relatively short distance upstream from the gage.

Because warming occurs from south to north in the spring and the river flows north to south, snowmelt peaks are difficult to follow downstream. The effect of this is that the peaks will occur within a few days of each other through the whole reach and the downstream peaks may even occur first.

Due to physical changes that have occurred on the river during recent years (bridge and levee construction, increased occurrance of log jams due to dutch elm disease, and so forth), the entire period of record was not analyzed. Because water year 1969 was a year of record peak flows, the analysis included the period from water year 1969 through water year 1981.

Detailed discussions are presented for particular flows during water years 1969, 1970, and 1972 to show the variation in traveltimes of flood waves of different magnitudes. These particular years were chosen because the Stratford and Mitchell gages were operative through water year 1972. All references to peaks in the following discussion refer to maximum daily discharge.

Discussion

Water Year 1969

In 1969, a negative peak (reverse flow = -1,750 ft^3/s) was recorded on the James River at Columbia on April 11. This resulted from Elm River inflows (a peak flow of 11,900 ft^3/s was recorded on the Elm River at Westport on April 10). Reverse flow at Columbia ended on April 14 and the James River peaked at 4,570 ft^3/s on April 22.

At the gage near Stratford, the James River peaked at 4,820 ft^3/s on April 24. This would indicate a traveltime of 2 days between Columbia and Stratford for a flow of this magnitude. Although the river mileage between Columbia and Stratford is 79 miles, a flow of this magnitude would be mostly overbank flow and the effective reach length would be considerably less.

At Ashton, a maximum daily reverse discharge of -2,100 ft^3/s was recorded on the James River on April 9. The reverse flow started on April 6 and ended on April 12 and resulted from Snake Creek inflows (a peak of 6,650 ft^3/s was recorded on Snake Creek near Ashton on April 11). The peak flow for the James River at Ashton was 5,670 ft^3/s on April 24. The river mileage between Stratford and Ashton is 45 miles (considerably less for overbank flow). It is possible that, for a flow of this magnitude, the traveltime could be less than 1 day.

At the gage near Redfield, the James River peaked at 7,280 ft^3/s on April 13. The hydrograph shows a recession of flow through April 19 to a minimum of 4,660 ft^3/s and then increasing flow until a secondary peak of 6,260 ft^3/s on April 24. The April 13 peak of 7,280 ft^3/s was due to inflows from Snake Creek (peak of 6,650 ft^3/s on April 11) and Turtle Creek (peak of 7,120 ft^3/s on April 7). The April 24 peak at the Redfield gage is only slightly higher than the April 24 peak that occurred at Ashton. Considering that the reach length is only 19 miles, it is possible that the traveltime between Ashton and Redfield is less than 1 day for the peak of a flow of this magnitude.

At Huron, the river peaked at 8,940 ft^3/s on April 12, receded to 5,650 ft^3/s on April 22 and 23, and then had a secondary peak of 5,980 ft^3/s on April 27. The initial peak on April 12 can probably be attributed to the combined effects of tributary inflows and direct drainage to the river since this peak at Huron occurred 1 day prior to the peak at Redfield. The secondary peak on April 27 would indicate a 3-day traveltime between Redfield and Huron, a distance of 62 river miles.

At Forestburg, the river peaked at 12,200 ft^3/s on April 10, receded to 5,400 ft^3/s on April 25, and then had secondary peaks of 6,010 ft^3/s on April 28 and 5,980 ft^3/s on May 1. The reach length is 43 miles and the hydrograph indicates a 4-day traveltime between Huron and Forestburg.

At Mitchell, the river peaked at 13,200 ft^3/s on April 11, receded to 6,100 ft^3/s on April 25, rose to a peak of 6,600 ft^3/s on April 28, receded to 5,900 ft^3/s on April 30, and then peaked again at 6,400 ft^3/s on May 2. The hydrograph indicates a

1-day traveltime for a peak of a magnitude of 12,000-13,000 ft^3/s. The peak on May 2 also indicates a traveltime of 1 day for a peak of 6,400 ft^3/s. The reach length between Forestburg and Mitchell is 55 river miles.

At Scotland, the river peaked at 13,900 ft^3/s on April 13, receded to 5,670 ft^3/s on May 1, and then had a secondary peak of 5,930 ft^3/s on May 7 and 8. This would indicate a 2-day traveltime for the initial peak (more than 13,000 ft^3/s) and a 5-day traveltime for the secondary peak (slightly less than 6,000 ft^3/s). The reach length between Mitchell and Scotland is 83 miles.

Water Year 1970

On December 10, 1969, the James River at Columbia peaked at 417 ft^3/s. Streamflow records indicate a stream gain of 10,370 acre-feet between the gages at LaMoure, N.Dak., and Columbia, S.Dak., during December 1969. Operation records for Sand Lake National Wildlife Refuge indicate a net change in storge of -12,300 acre-feet during December 1969. Streamflow records for local tributaries (Maple River and Elm River) indicate little or no flow. Therefore, it is concluded that the peak at Columbia was caused by releases from Sand Lake National Wildlife Refuge.

At the gage near Stratford, the river peaked at 340 ft^3/s on December 15, 16, and 17. This would indicate a 5- to 7-day traveltime between Columbia and Stratford for a flow of this magnitude.

At Ashton, the peak was 310 ft^3/s on December 24, 25, and 26, indicating a 9-day traveltime between Stratford and Ashton.

At Redfield, the river peaked at 310 ft^3/s on December 27 and 28, indicating a 2- to 3-day traveltime between Ashton and Redfield. Records indicate that tributary inflows in the vicinity of Redfield were virtually zero during this period.

At Huron, the river peaked at 323 ft^3/s on December 31. Although a slight increase in the peak is indicated, the river receded to 310 ft^3/s (same as peak at Redfield) on the following day (January 1) and a traveltime of 4 days is indicated by the hydrograph.

The river peaked at 320 ft^3/s near Forestburg on January 3. This indicates a 3-day traveltime between Huron and Forestburg.

At Mitchell, the river peaked at 290 ft^3/s on January 4 and 5, indicating a 1- to 2-day traveltime between Forestburg and Mitchell. Gaged flows from intervening tributaries continued to be virtually zero during this period.

At Scotland, the river peaked at 240 ft^3/s on January 5, receded to 210 ft^3/s on January 10 and then rose to 220 ft^3/s on January 12 before beginning a gradual recession for the rest of the month. If this secondary peak can be attributed to the Sand Lake release, it would indicate a 7-day traveltime between Mitchell and Scotland.

The above analysis indicates a 30- to 35-day traveltime between Columbia and Scotland for a flow of 200 to 400 ft^3/s.

Water Year 1972

On April 7, 1972, the James River at Columbia peaked at 705 ft^3/s. During March 18-22, the river at Columbia was in a reverse flow condition, peaking at -1,180 ft^3/s. This was caused by inflows from the Elm River (peak of 3,500 ft^3/s on March 19).

At the gage near Stratford, the James River peaked at 978 ft^3/s on April 7, receded to 957 ft^3/s on April 11, and then rose to 973 ft^3/s on April 12 and 13 before beginning a gradual decline. Assuming that the initial peak was caused by intervening tributary inflows and direct drainage to the river, the traveltime between Columbia and Stratford was 5-6 days.

At Ashton, the river peaked at 797 ft^3/s on April 19, and then receded during the remainder of the month. This would indicate a traveltime of 6-7 days between Stratford and Ashton.

At the gage near Redfield, the peak flow was 1,970 ft^3/s and was recorded on March 21. This peak was caused by tributary inflows from Turtle Creek (peak of 1,000 ft^3/s on March 19) and Snake Creek (the South Fork Snake Creek near Athol had a peak of 1,120 ft^3/s on March 17). The river then receded to 899 ft^3/s on April 4 and then rose to 947 ft^3/s on April 17 before beginning a gradual decrease for the remainder of the month. The flow at Redfield during April subsequent to the peak on April 17 is greater than the peak recorded at Ashton (797 ft^3/s on April 19) and it is not possible to detect the traveltime between Ashton and Redfield for this particular flow from the hydrograph.

At Huron, the river peaked at 2,480 ft^3/s on March 23. This would indicate a traveltime of 2 days between Redfield and Huron for this particular flow. Again it is not possible to determine when the 797 ft^3/s peak at Ashton on April 19 actually passed Huron.

At the gage near Forestburg, the river peaked at 2,450 ft^3/s on March 26. This would indicate a 3-day traveltime between Huron and Forestburg.

The peak flow at Mitchell was 2,140 ft^3/s on March 30, indicating a 4-day traveltime between Forestburg and Mitchell.

At the gage near Scotland, the peak was 2,050 ft^3/s on April 3 and 4, indicating a 4-5 day traveltime between Mitchell and Scotland.

Summarizing the analysis for 1972, the traveltime for a flow of 700-900 ft^3/s between Columbia and Ashton appeared to be 11-13 days. The traveltime for a different flow (2,000-2,500 ft^3/s) between Redfield and Scotland appeared to be about 13-14 days. In 1970 (previously discussed), the traveltimes between the respective stations were 17-18 days and 15-16 days for a flow of a smaller magnitude.

Conclusions

The traveltime of flood-waves in the James River is, of course, dependent on the magnitude of the flow under consideration. The hydrographs of the 1969 flow, where peaks ranged from about 4,000 ft^3/s in the upper James to almost 14,000 ft^3/s in the lower James, indicate a flood-wave traveltime of about 12-15 days between Columbia and Scotland. In 1972, where peaks ranged from about 700 to about 800 ft^3/s in the upper James, the flood-wave traveltime between Columbia and Ashton appears to be 11-13 days. For a slightly larger flow in 1972, the flood-wave traveltime between Redfield and Scotland appears to be 13-14 days. In 1970, a smaller flow (200-400 ft^3/s) appears to have had a 30- to 35-day traveltime between Columbia and Scotland. The cumulative traveltime below Columbia for the 1969, 1970, and 1972 flows is presented in figure 11.

Mean Velocity

Procedure

Mean velocities were computed for 23 locations on the James River in South Dakota using the data obtained from the discharge measurements that were made in April-June 1982. The mean-velocity data and reach lengths were used to compute traveltimes for various reaches of the river. Traveltime based on mean velocity is an indication of transport time and is referred to as water traveltime.

Discussion

The total water traveltime between Columbia and Scotland equals 31 days using the mean-velocity data (table 6). The hydrograph analysis for a flow of a similar magnitude indicated a flood-wave traveltime of 24-27 days. These results are very comparable in that the hydrograph analysis was an evaluation of flood-wave traveltime (celerity), which usually is 1.0 to 1.3 times faster than mean velocity.

Conclusions

The analysis of streamflow hydrographs for water years 1970-81 generally indicates flood-wave traveltimes ranging from 20 to 35 days between Columbia and Scotland. The hydrographs of the record spring flows of 1969 indicate a 12- to 15-day flood-wave traveltime for the same reach. Computation of traveltime for the same reach using mean-velocity data and reach lengths indicated a 31-day water traveltime.

Excluding large flows such as occurred in the spring of 1969, the average traveltime between Columbia and Scotland is 25-30 days for most flows.

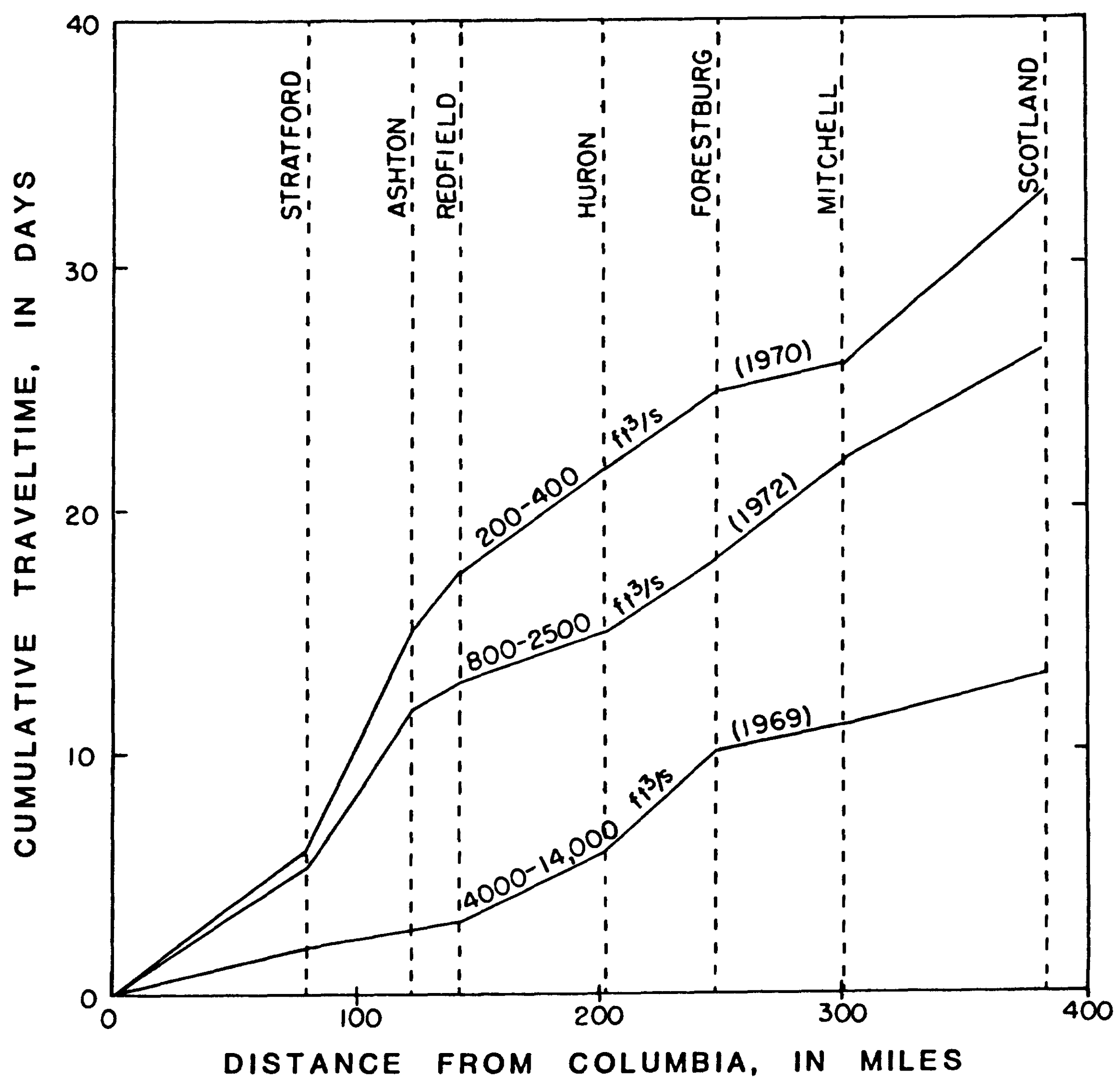


Figure 11.--Flood-wave traveltime for the James River within South Dakota.

Table 6.—Traveltime computations for the James River based on mean velocity (1982 discharge measurements)

Location	Approximate reach length (miles)	Approximate discharge (cubic feet per second)	Mean velocity (feet per second)	Water travel-time (days)	Water travel-time by reach (days)
Columbia gaging station					
	35	190	0.31	6.9	
U.S. Highway 12					
	16	230	.27	3.6	14.0
Moccasin Creek					
	28	1/ 310	1/ .49	3.5	
Stratford gaging station					----
	9	1,050	.84	.7	
Mud Creek					2.4
	36	1/ 960	1/ 1.28	1.7	
Ashton gaging station					----
	6	800	1.24	.3	
Snake Creek					
	8	930	1.80	.3	.8
Turtle Creek					
	5	2/ 930	2/ 1.80	.2	
Redfield gaging station					----
	35	2/ 930	2/ 1.80	1.2	
James Diversion Dam					4.4
	27	1/ 880	1/ .51	3.2	
Huron gaging station					----
	43	940	1.56	1.7	1.7
Forestburg gaging station					----
	51	920	1.03	3.0	3.0
Mitchell gaging station					----
	29	895	.95	1.9	
State Highway 42					
	21	880	1.10	1.2	
State Highway 44					4.7
	23	890	1.29	1.1	
Olivet					
	10	2/ 890	2/ 1.29	.5	
Scotland gaging station					
Total				31.0	31.0

1/ Average of more than one discharge measurement and more than one mean velocity computation.

2/ No discharge measurement in reach, upstream measurement used for traveltime computation.

ANALYSIS OF STREAM GAINS AND LOSSES

Procedure

The James River, especially the reach within the Lake Dakota Plain, has stream losses under certain hydrologic conditions. The purpose of this analysis was to graphically depict stream gains and losses and to analyze these gains and losses.

Mean-monthly streamflow data for eight main-stem gaging stations between LaMoure, N. Dak., and Scotland, S. Dak., plus five gaged tributaries, were used to analyze gains and losses. The procedure was similar to that used by Koch (1970) whereby the monthly net gain or loss for a particular reach was computed as the difference between the flow for the downstream station and the flow for the upstream station, minus the flow for any tributaries present in the reach. A positive value indicated a net gain for the reach in a particular month and a negative value indicated a net loss.

The monthly net gains or losses were then accumulated over time to ascertain whether or not the stream gains or losses were real or apparent. Real stream gains or losses can result from diversions, precipitation runoff, ground-water discharge or recharge, and evapotranspiration. Apparent stream gains or losses can result from travel lag times, overbank flood storage, bank storage, and reservoir operation.

Discussion

LaMoure, N. Dak. to Columbia, S. Dak.

Historic records from water year 1951 through water year 1981 were used to analyze this reach. The reach is approximately 96 miles in length, the contributing drainage area within the reach is about 2,260 square miles, and the reach contains Sand Lake National Wildlife Refuge, which includes Sand Lake (capacity = 18,000 acre-feet, and surface area = 6,050 acres at spillway elevation 1,287.52 feet above NGVD of 1929) and Mud Lake (capacity = 6,600 acre-feet, and surface area = 4,950 acres at spillway elevation 1,288.23 feet above NGVD of 1929). The area-capacity data are based on unpublished area-capacity curves prepared by the Bureau of Reclamation in 1981. The refuge will be discussed in greater detail in a later section of this report.

A plot of the cumulative gains and losses in the reach for water year 1951 through water year 1981 is shown in figure 12. The results are tabulated in table 14 (Supplemental Information section at back of report). Several periods of relatively constant stream loss are shown on the plot, the longest of which is between June 1954 and February 1962 when the loss averaged slightly more than 10,000 acre-feet per year or about 835 acre-feet per month. The periods and associated losses include:

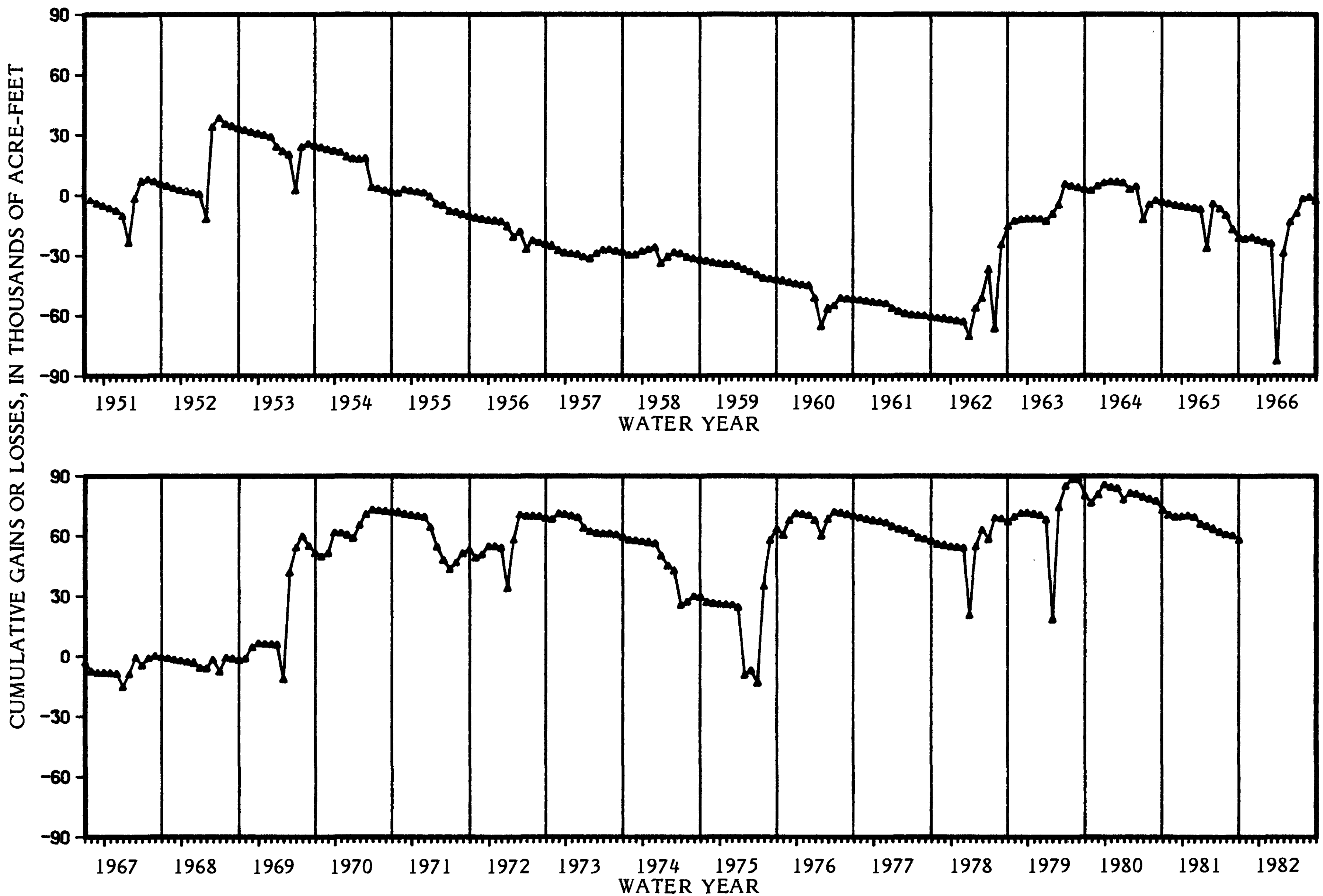


Figure 12.--Cumulative stream gain or loss along the James River between LaMoure, N. Dak., and Columbia, S. Dak., water years 1951-81.

From	To	Loss (acre-feet per month)
July 1951	March 1952	930
July 1952	May 1954	770
June 1954	February 1965	835
August 1964	March 1965	625
June 1970	February 1971	450
May 1972	February 1974	690
June 1976	February 1978	900
December 1979	September 1981	1,310

Periods of substantial stream gain include May 1952, May-June 1962, May-July 1969, and July-September 1975 which were high-runoff periods. Periods of substantial stream loss, probably resulting from filling of Sand and Mud Lakes, include June 1954, March-June 1974, and April 1975. Periods of apparent stream loss, where the previous month's loss generally equals the present month's gain (probably caused by travel time), include June-July 1953, April-May 1965, March-April 1966, March-April 1978, and April-May 1979.

Further interpretations of the results for water year 1951 through water year 1968 are contained in Koch's work (1970). These same interpretations can be extended to water year 1969 through water year 1981.

Columbia to Stratford

Historic records from water year 1951 through water year 1972, when the Stratford gage was discontinued, were used to analyze this reach. The flows for the Elm River at Westport also were included in the evaluation. The reach is approximately 79 miles long and the contributing drainage area within the reach is between 1,750 and 2,940 square miles (non-contributing drainage area is not available for the James River near Stratford). The Elm River at Westport flows represent 1,170 square miles of contributing drainage area, which is 40 to 67 percent of the total contributing drainage area within the reach. The conveyance capability of the James River is very restricted in this reach. The bankfull channel capacity of the river near the confluence with Moccasin Creek is estimated to be as little as 200 ft^3/s.

A plot of the cumulative gains and losses for water year 1951 through water year 1972 is shown in figure 13. The results also are tabulated in table 15. The general downward trend of the plot indicates that this reach was losing water for most of the period of record. During September 1953 to February 1962, the river lost water at a rate of about 365 acre-feet per month.

Major stream losses are noted during March-May 1960 (20,572 acre-feet), March-October 1962 (28,347 acre-feet), March-September 1966 (16,324 acre-feet), and April-September 1969 (40,104 acre-feet). Major flooding occurred in the reach in each of these years. The losses resulted from entrapment of the flood flows in the overbank lowlands and subsequent evaporation or transpiration before the water could return to the river. This entrapment is due, in part, to the existance of man-made levee systems, which are overtopped during major floods.

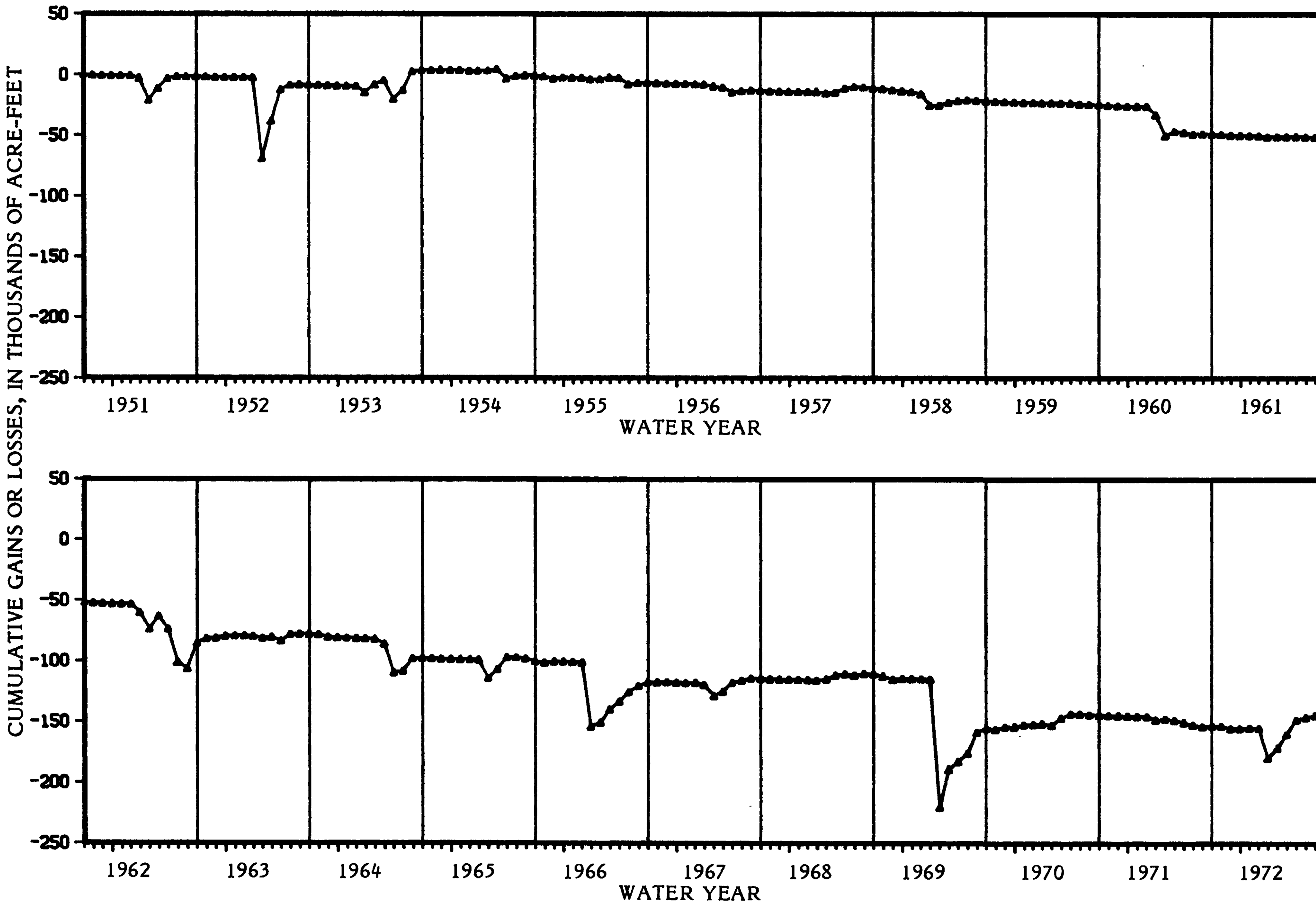


Figure 13.--Cumulative stream gain or loss along the James River between Columbia and Stratford, S. Dak., water years 1951-72.

Smaller losses are indicated during the spring and early summer of water years 1952, 1954, 1955, 1956, 1958, and 1964. These losses probably can be attributed to transpiration of bank storage. Apparent losses are indicated during water years 1951 through 1953, water years 1962 through 1967, water year 1969, and water year 1972. The lag time required for these apparent losses to return to the system ranges from 2 to 6 months. Considering the characteristics of the river within the reach, this time does not seem unreasonable and probably can be attributed to bank storage and overbank storage of floodflows.

Stratford to Ashton

The period of record used to analyze the reach was limited to water years 1956 through 1969 in order to coincide with the period of record for Mud Creek near Stratford which is the major tributary inflow within this reach. The reach is about 45 miles long and the contributing drainage area within the reach is less than 1,000 square miles. The Mud Creek basin represents 460 square miles of contributing drainage area.

A plot of the cumulative gains and losses for the reach is shown in figure 14. The results also are tabulated in table 16. Major stream losses are indicated in water years 1962 and 1966, which were periods of major flooding. Apparent losses in water years 1964, 1965, and 1967 were returned to the system in 1-2 months. A substantial stream gain is indicated in the spring of 1969 which was a high runoff period. The results for the reach are identical to those reported by Koch (1970) and will not be discussed further in this report.

Ashton to Redfield

Again, the period of record used in the analysis was limited to water years 1956 through 1969 in order to coincide with the period of continuous record for Snake Creek near Ashton. Tributary flows for Turtle Creek at Redfield also were included in the analysis of the reach. The length of the reach is 19 miles and the contributing drainage area within the reach is 3,390 square miles. The Snake Creek basin represents 52 percent of the contributing drainage area and the Turtle Creek basin represents as much as 45 percent of the contributing drainage area (the noncontributing drainage area for Turtle Creek is not available).

A plot of the cumulative gains and losses for the reach is shown in figure 15 and a tabulation of the results is presented in table 17. The plot shows that, for water year 1956 through mid-water year 1962, the James River had virtually no net gain or loss within the reach. This is understandable for water years 1956, 1958, 1959, and 1961 in which total annual precipitation at Redfield was normal or significantly less. However, annual precipitation at Redfield was 10.19 inches greater than normal during water year 1957, which should result in a major stream gain similar to water year 1962 (net gain = 13,120 acre-feet) when total precipitation at Redfield was 7.14 inches greater than normal. A review of precipitation records reveals that the distribution of monthy precipitation was much more uniform during water year 1957 than during water year 1962, and the January-March precipitation was much greater during 1962. During water year 1962, about 55 percent of the total precipitation fell in May and June (the two maximum months) whereas during water year 1957, only about 37 percent of the total precipitation fell in the two maximum months (April and May). In addition, the two maximum months of precipitation were preceded by only 0.67 inch of precipitation in

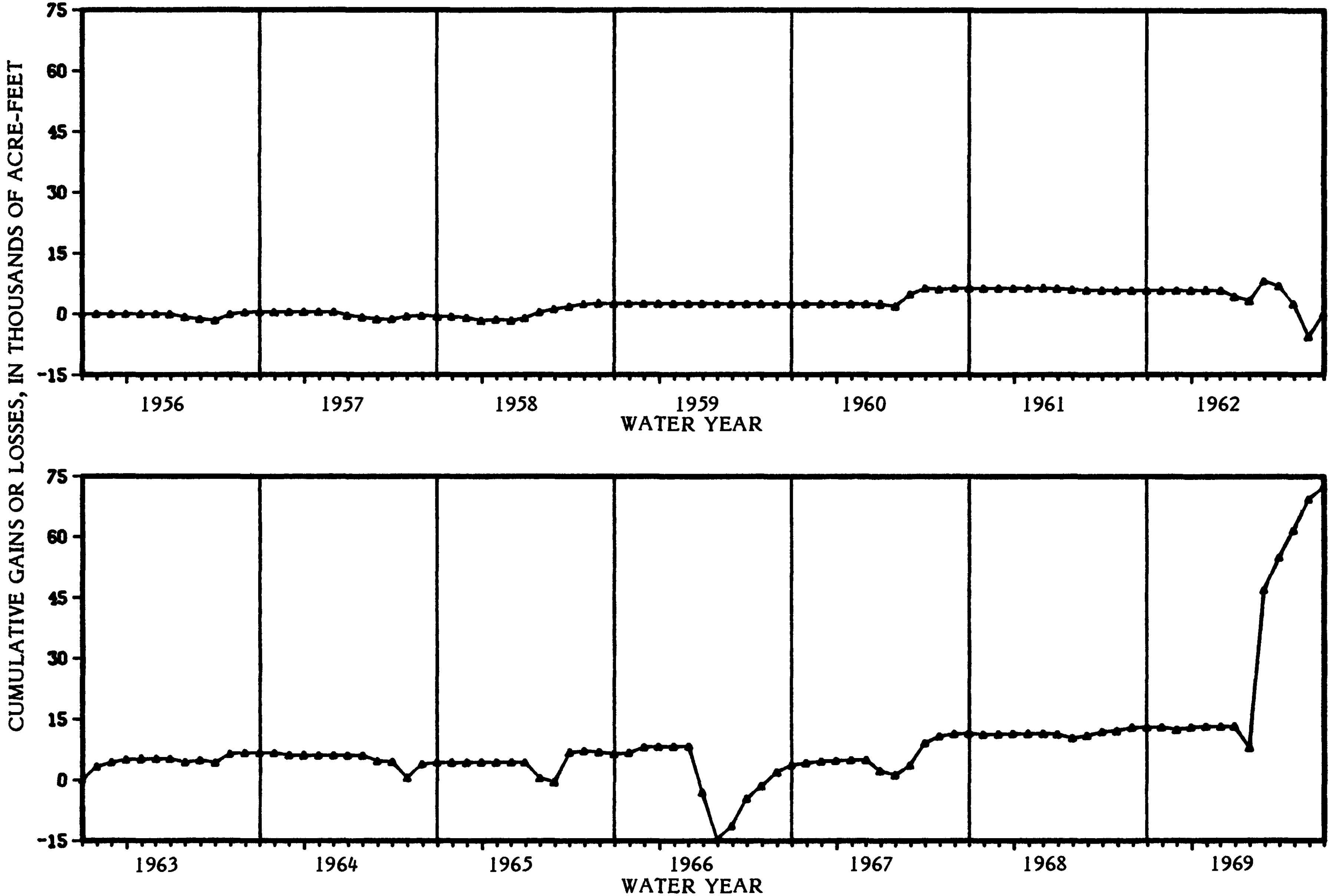


Figure 14.--Cumulative stream gain or loss along the James River between Stratford and Ashton, S. Dak., water years 1956-69.

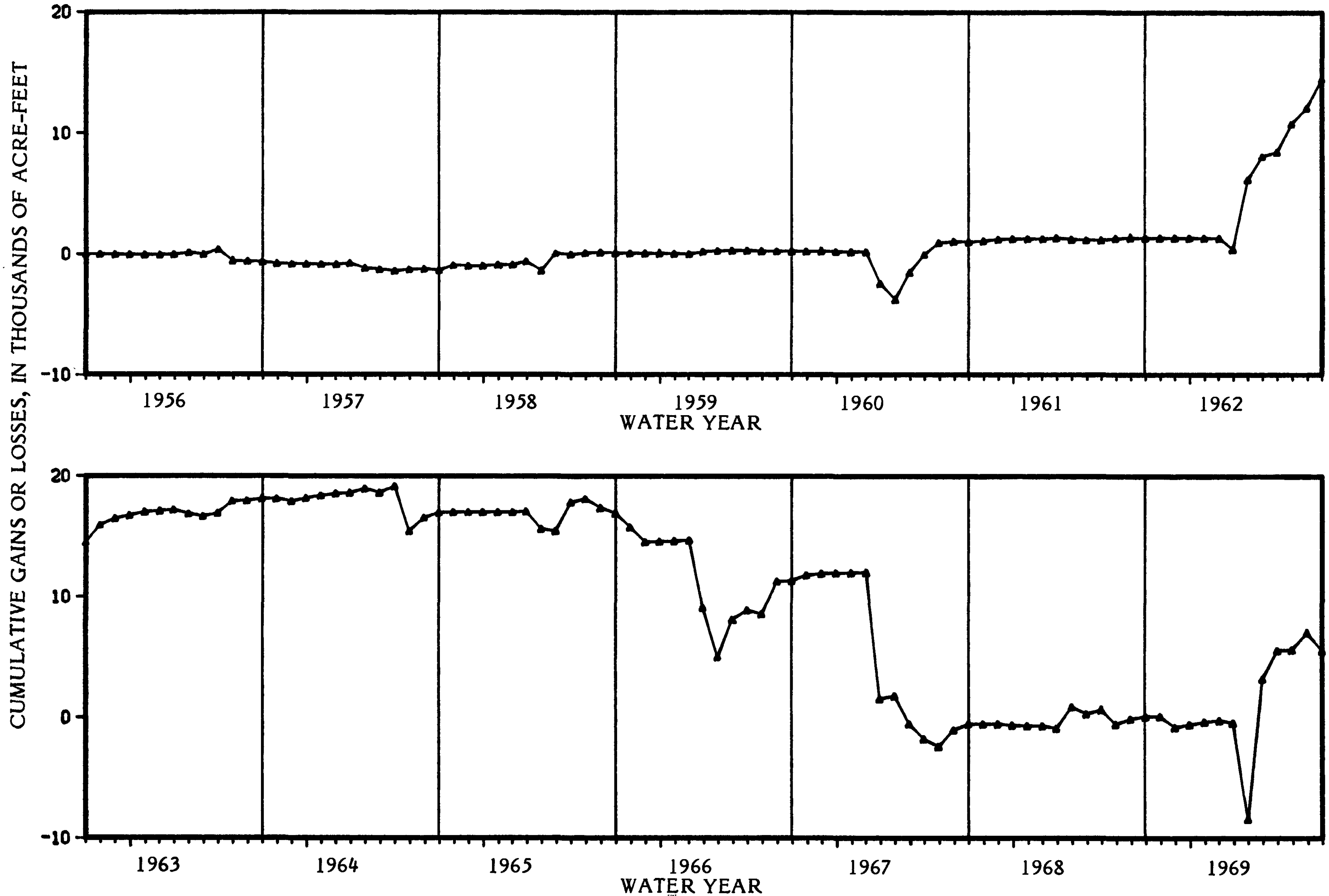


Figure 15.--Cumulative stream gain or loss along the James River between Ashton and Redfield, S. Dak., water years 1956-69.

the preceeding months in 1957. In water year 1962, the two maximum months were preceeded by 4.68 inches of precipitation. Therefore, the saturated soil conditions of spring and early summer of water year 1962 provided for much more runoff than in water year 1957.

A major stream loss (3,376 acre-feet) is indicated between February and August of 1966, which was a year of significant flooding in the upper James River. Another major stream loss (10,462 acre-feet) is shown in March of 1967. The reason for this loss is unknown.

Redfield to Huron

Historic records from water year 1951 through water year 1981 were used to analyze the reach between Redfield and Huron. The reach length is about 62 miles and the contributing drainage area within the reach is about 1,810 square miles. There are no long-term, continuous flow records for any tributaries within the reach.

The data in figure 16 indicate that the reach is a continually gaining reach. Significant streamflow gains are shown for water years 1952, 1953, 1960, 1962, 1969, 1972, and 1978, which were years of greater than normal streamflow, and subsequent flooding, on the James River. The results also are tabulated in table 18.

Huron to Forestburg

Data for water years 1951 through 1981 also were used to analyze the reach between Huron and Forestburg. Flows from Sand Creek near Alpena were included in the analysis. The reach length is about 39 miles and the contributing drainage area within the reach is about 1,000 square miles. The flows from Sand Creek represent about 13 percent of the contributing drainage area within the reach.

A plot of the cumulative gains for the reach is shown in figure 17. The data indicate that the reach is a continually gaining reach with significant streamflow gains in water years 1952, 1960, 1962, 1969, and 1972, which were years of greater than normal streamflow. The results also are tabulated in table 19.

Forestburg to Scotland

This reach also was analyzed for water years 1951 through 1981. The only tributary with long-term records (1955-81) within the reach is Firesteel Creek near Mount Vernon. However, Firesteel Creek is regulated by Lake Mitchell prior to its confluence with the James River and it was, therefore, not included in the analysis. The reach length between Forestburg and Scotland is about 138 miles and the contributing drainage area is about 2,950 square miles.

The reach is a continually gaining reach and the cumulative gains are plotted in figure 18. Notable gains are again indicated in water years 1960, 1962, and 1969. From water years 1956 through 1959, the reach gained at a rate of about 22,500 acre-feet per year. During water years 1963 through 1968, the rate of gain was about 34,100 acre-feet per year and during water years 1974 through 1977, the river gained at a rate of about 16,700 acre-feet per year. The results also are tabulated in table 20.

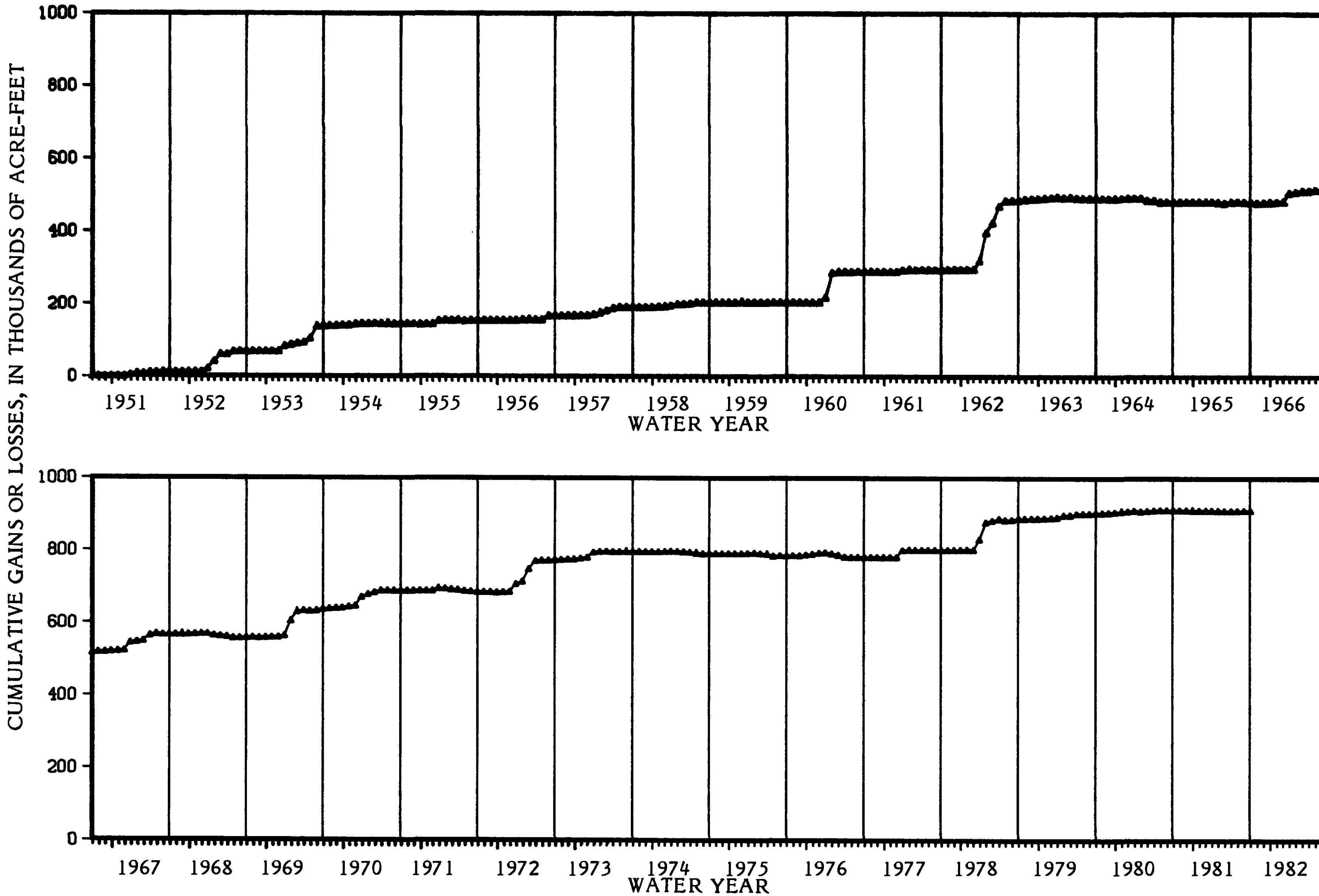


Figure 16.--Cumulative stream gain or loss along the James River between Redfield and Huron, S. Dak., water years 1951-81.

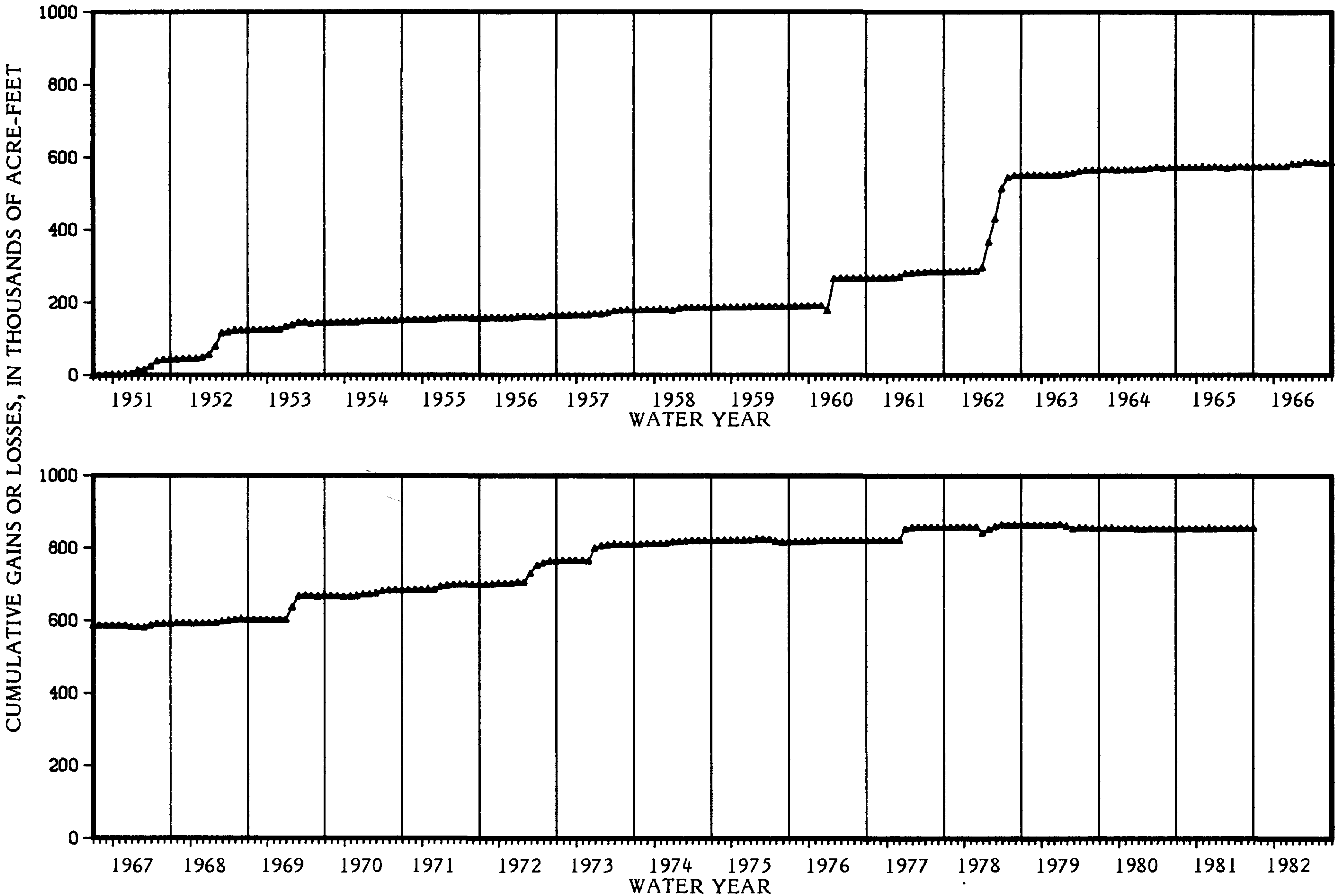


Figure 17.--Cumulative stream gain or loss along the James River between Huron and Forestburg, S. Dak., water years 1951-81.

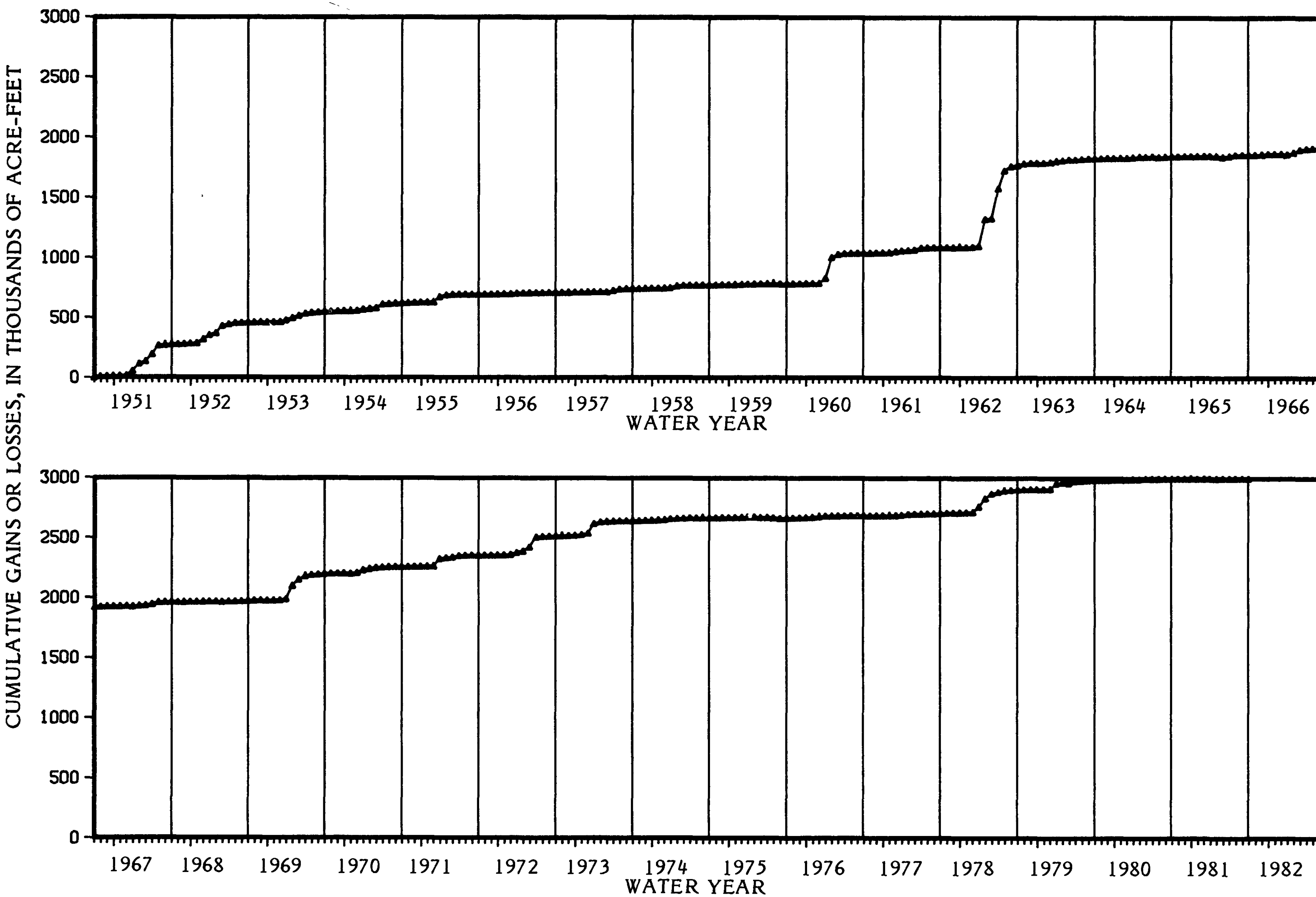


Figure 18.--Cumulative stream gain or loss along the James River between Forestburg and Scotland, S. Dak., water years 1951-81.

Conclusions

The results of the gain-loss study indicate that the James River has periods of real and apparent stream loss as well as periods of real stream gain. The results for the reach within the Lake Dakota Plain (LaMoure to Redfield) are markedly different from the results for the river south of Redfield. Generally, the river within the Lake Plain loses discharge with distance, whereas the downstream reach gains discharge with distance.

Considering the physical characteristics of the upper James, and the availability of flow records for major tributaries, the trends shown by the gain-loss study are thought to be a reasonable indication of actual conditions. The trend of gradual loss probably is due to bank storage and evapotranspiration of water from the river. These losses can become significant when flows are preceeded by extended periods of no flow (when the river is dry). Major losses are associated with the occurrance of flooding when water is trapped in the overbank area and evaporated or transpired before it can re-enter the river. The trend of gradual gains for the lower James probably is indicative of actual conditions although the lack of tributary records probably resulted in an over-estimation of gains and an under-estimation of losses.

The analysis could be improved by giving more detailed consideration to tributary inflows. In certain instances, it was necessary to decrease the period of analysis in order to coincide with the period of record for the tributaries. For instance, the analysis for the reach between Ashton and Redfield was limited to water years 1956-69 to coincide with the historic record for Snake Creek. If the records for the tributaries were extended through statistical means, the gain-loss analysis could then be made for the period coinciding with the period of record for the main-stem stations (water years 1951-81 in this instance). If flows for ungaged tributaries were estimated through regression or correlation techniques, the effects of these flows also could be included in the analysis.

ANALYSIS OF FLOOD FREQUENCY

Procedure

Statistical flood-frequency analyses of annual peak flows were made for the main-stem gaging stations and the gaged tributaries with 10 or more years of record. The analyses were made using the log-Pearson Type III frequency distribution following procedures recommended by the U.S. Water Resources Council (1981). The results are summarized in tabulations which list the magnitude of instantaneous peak flow for recurrance intervals of 1.25 years, 2 years, 5 years, 10 years, 25 years, 50 years, and 100 years; the associated annual exceedance probabilities are 80 percent, 50 percent, 20 percent, 10 percent, 4 percent, 2 percent, and 1 percent, respectively.

Discussion

Main-Stem Locations

The results of the flood-frequency analyses made on the main-stem gages using records subsequent to water year 1954 (when Jamestown Reservoir became operational) are summarized in table 7. Jamestown Reservoir is a Bureau of Reclamation-constructed reservoir located at Jamestown, N. Dak. The total capacity is 220,978 acre-feet, of which 185,435 acre-feet are for flood control (U.S. Water and Power Resources Service, 1981).

The frequency analyses for the James River at Columbia reflects the attenuation of flood peaks between LaMoure and Columbia. This is due to the physical characteristics of the river in this reach and the damping effects of Dakota Lake, Mud Lake, and Sand Lake. Comparison of the analyses for Columbia and Stratford shows additional attenuation of flood peaks. This could be due, in part, to the fact that the period of record for Stratford is not the same as the period of record for Columbia. However, it is more likely that this is caused by the characteristics of the river between Columbia and Stratford. Channel capacities in this reach are as little as 200 ft^3/s and frequent overbank flooding occurs. This overbank flooding tends to attenuate the peaks.

The analyses for Mitchell needs to be interpreted with caution due to the short period of record (13 years). The peak flows of record for each of the main-stem stations are presented in table 1.

Tributary Locations

Results of the frequency analyses for the gaged tributaries within the James River drainage in South Dakota are presented in table 8. The results indicate that there is potential for substantial peak flows within the tributary system. The peak flows of record for the various stations are presented in table 2.

Conclusions

When the results of the main-stem frequency analyses are considered in conjunction with the channel capacities, it can be concluded that the recurrence interval for overbank flooding on the James River in South Dakota is 10 years or less. In the vicinity of Stratford, which is the most restricted area within South Dakota, the recurrence interval for flooding is less than 2 years.

Concerns relating to upstream regulation have been expressed on numerous occasions by local interests along the upper James River within South Dakota. Additional detailed studies (additional frequency analyses, flow duration, and so forth) are needed to formally assess the effects that Jamestown and Pipestem Reservoirs have on the flow regime in South Dakota.

Table 7.--Magnitude and probability of instantaneous peak flow at streamflow-gaging stations on the James River subsequent to closure of Jamestown Reservoir in water year 1954

Station	Period of record (water years)	Discharge, in cubic feet per second, for recurrence interval, in years, and annual exceedance probability, in percent							
		Years: Percent:	1.25 80	2 50	5 20	10 10	25 4	50 2	100 1
James River at LaMoure, N. Dak.	1954-80		280	800	2,080	3,330	5,360	7,190	9,290
James River at Columbia, S. Dak.	1954-80		90	350	1,100	1,890	3,170	4,320	5,600
James River near Stratford, S. Dak.	1/ 1954-77		120	350	980	1,620	2,740	3,810	5,100
James River at Ashton, S. Dak.	1954-80		170	420	1,030	1,680	2,870	4,070	5,600
James River near Redfield, S. Dak.	1954-79		270	690	1,750	2,820	4,670	6,430	8,570
James River at Huron, S. Dak.	1954-80		480	1,140	2,740	4,370	7,230	10,000	13,500
James River near Forestburg, S. Dak.	1954-80		430	1,220	3,440	5,930	10,600	15,500	21,800
James River near Mitchell, S. Dak.	2/ 1954-72		760	1,640	3,670	5,670	9,130	12,500	16,700
James River near Scotland, S. Dak.	1954-80		790	1,900	4,660	7,480	12,400	17,300	23,300

1/ Period of record not continuous (1954-72, 1977).
2/ Period of record not continuous (1954-58, 1965-72).

Table 8.--Magnitude and probability of instantaneous peak flow at streamflow-gaging stations on tributaries within the James River basin in South Dakota

Station	Period of record (water years)	Drainage area: Total	Drainage area: Contributing	Discharge, in cubic feet per second, for recurrence interval, in years, and annual exceedance probability, in percent — Years: 1.25 / Percent: 80	2 / 50	5 / 20	10 / 10	25 / 4	50 / 2	100 / 1
Maple River at N. Dak.-S. Dak. State line.	1957-80	750	480	88	340	1,250	2,400	4,730	7,270	10,600
Elm River at Westport, S. Dak.	1947-80	1,680	1,170	150	690	2,760	5,420	10,700	16,200	23,200
Mud Creek near Stratford, S. Dak.	1956-77	730	460	8	50	260	590	1,330	2,190	3,380
S. Fork Snake Creek near Athol, S. Dak.	1950-73	1,820	1,090	17	110	650	1,620	4,260	7,910	13,700
Snake Creek near Ashton, S. Dak.	1/ 1956-79	2,620	1,770	27	170	940	2,210	5,290	9,110	14,700
Wolf Creek near Ree Heights, S. Dak.	1960-80	265	3/	--	12	150	510	1,650	3,380	6,250
Turtle Creek near Tulare, S. Dak.	2/ 1954-80	1,120	3/	6	72	760	2,420	7,970	16,800	32,200
Medicine Creek near Zell, S. Dak.	1960-80	210	3/	23	120	570	1,220	2,690	4,400	6,760
Turtle Creek at Redfield, S. Dak.	1946-72	1,540	3/	39	220	1,180	2,800	6,940	12,400	20,700
Sand Creek near Alpena, S. Dak.	1950-80	240	3/	28	210	1,080	2,270	4,580	6,880	9,640
Firesteel Creek near Mount Vernon, S. Dak.	1956-80	540	3/	19	210	1,700	4,580	12,200	22,100	36,700

1/ Period of record not continuous (1955-69, 1976-79).
2/ Period of record not continuous (1954-56, 1965-80).
3/ Determination of contributing and noncontributing drainage area has not been made.

REVIEW OF GROUND WATER - SURFACE WATER RELATIONSHIPS

The U.S. Geological Survey, in cooperation with the South Dakota Geological Survey, has made water-resource studies for the counties of Brown, Beadle, Sanborn, Hanson, Davison, and Yankton. The only South Dakota counties transversed by the James River in which studies have not been made are Spink and Hutchinson.

Following is a review of the findings of the studies which relate to the potential for interaction between the James River and underlying aquifers. Comments concerning aquifer recharge and discharge apply only to the specific county being discussed. Additional aquifer recharge or discharge may occur outside the county under discussion.

Brown County

Koch and Bradford (1976) report that three major aquifers are contained within glacial outwash deposits in Brown County. The aquifers, named the Deep James, Middle James, and Elm, underlie the James River in southern Brown County and in the northern part of the county upstream from Columbia. Cross sections of the topographic and stratigraphic relations of these aquifers (Koch and Bradford, 1976, figure 13) do not indicate any areas where there is hydraulic connection with the James River. Recharge to the aquifers is thought to be by infiltration and percolation of snowmelt and precipitation through overlying materials and by subsurface inflow from Spink and Marshall Counties.

Discharge from the Deep James aquifer is by upward leakage into till. The Middle James aquifer discharges by percolation into the Deep James aquifer and by eastward flow into the Lake Dakota plain sediments and into till. Natural discharge from the Elm aquifer is into the Elm River, Foot Creek, the Middle James aquifer, by eastward flow into lacustrine deposits underlying the Lake Dakota plain, and into the atmosphere by evapotranspiration.

Lithologic sections (Koch and Bradford, 1976, figure 13) indicate very-fine or fine sands extending from 1 to 4 miles to the east of Sand and Mud Lakes, indicating a potential for interaction between these deposits and the lakes. Several shallow observation wells were installed by the U.S. Geological Survey and the Bureau of Reclamation in the early 1950's; however, these wells were not monitored during the period for which operating records are available on Sand and Mud Lakes. An assessment of concurrent data on lake levels and water levels in the observation wells might be used to determine if there is interaction between the lakes and the sand deposits.

The U.S. Geological Survey attempted to locate several of the wells in June 1982 in order to monitor water levels in the wells and compare these data with lake-level data. However, only a few wells were found and some of these were damaged or plugged. Due to the time constraints on the present study, attempts to make the existing wells operative or to attempt to locate additional wells were abandoned.

Beadle County

Howells and Stephens (1968) report three major aquifers located in unconsolidated surficial deposits in Beadle County. They are named the Warren, Floyd, and Tulare aquifers. The Tulare aquifer underlies the James River in northern Beadle County and the Floyd aquifer underlies the river in the central part of the county. In southern Beadle County, the river generally follows the divide between the Floyd and Warren aquifers.

Recharge to the aquifers is thought to be by infiltration of precipitation or ground-water inflow from adjacent areas. Discharge from the aquifers in the glacial drift in Beadle County is by evaporation and transpiration, and by leakage into bedrock aquifers in the Niobrara Formation and Codell Sandstone Member of the Carlile Shale, both of Cretaceous age. Perennial springs are found in five areas within the county; however, total discharge of all known springs is less than 100 gallons per minute. There is no base flow in the James River during periods of scant precipitation and it is therefore concluded that there is probably no significant interchange between the James River and underlying aquifers in Beadle County.

Sanborn County

Sanborn County is underlain by two major aquifers in the glacial drift, the Warren aquifer which underlies about 190 square miles in the western part of the county and the Floyd which underlies about 180 square miles in the northeastern part of the county (Steece and Howells, 1965). The aquifers are generally separated by the James River trench in northern Sanborn County.

The Warren aquifer has two areas of major recharge from infiltration of precipitation within Sanborn County--the outwash plain and dune sand areas south of Sand Creek between Woonsocket and Forestburg, and the outwash plain along Morris Creek (also known as Dry Run) west of Cuthbert. The Floyd aquifer does not receive recharge from infiltration of precipitation within Sanborn County. The recharge is thought to be from the northeast or east.

The Warren and Floyd aquifers both receive recharge from aquifers in the bedrock by water leaking into the permeable parts of the glacial drift through corroded casings of deep artesian wells.

Most of the natural ground-water discharge from the Warren aquifer is due to evaporation and transpiration. Two small perrenial springs were found along the James River. The Floyd aquifer is thought to have little natural discharge in Sanborn County. It is covered by 25 to 100 feet of relatively impermeable till, which decreases evapotranspiration to a relatively small quantity. No permanent springs or seeps from the Floyd aquifer were located during the well inventory. Steece and Howells (1965) did not discover any areas of significant interchange between the James River and underlying aquifers in Sanborn County.

Hanson and Davison Counties

Glacial aquifers in Hanson and Davison Counties include the Floyd, Plum Creek, Ethan, Warren, and Alexandria (D. S. Hansen, U.S. Geological Survey, written commun., 1982). The Floyd aquifer underlies 84 square miles in northern Hanson County, the Plum Creek aquifer underlies 27 square miles in southern Hanson County, the Ethan aquifer underlies 33 square miles in southern Davison County, the Warren aquifer underlies 21 square miles in northern Davison County, and the Alexandria aquifer underlies 31 square miles in eastern Hanson County.

Recharge to the Floyd aquifer is by inflow from an underlying aquifer (Precambrian Sioux Quartzite wash). Recharge to the Plum Creek aquifer is by infiltration of snowmelt and rainfall on Sioux Quartzite outcrops to the north. Recharge to the Ethan aquifer is by infiltration of snowmelt and rainfall and by discharge of ground water from the underlying Niobrara aquifer. The Warren aquifer is recharged by the Niobrara aquifer and by leakage from Lake Mitchell (located on Firesteel Creek) where the aquifer and the lake are in hydraulic connection. Natural discharge of the Warren aquifer is by subsurface outflow to Dry Run Creek and to the James River where it is hydraulically connected to the aquifer.

Two bedrock aquifers, the Niobrara and Codell, located in Hanson and Davison Counties are hydraulically connected to surface-water courses. The Niobrara aquifer is recharged by snowmelt and spring and early summer rains on an outcrop area on the flood plain of the North Fork of Twelve Mile Creek, and by infiltration of snowmelt and rain through the glacial till. Natural discharge from the Niobrara aquifer is by subsurface flow to outcrops east of Ethan and in the James River flood plain and subsequent evapotranspiration, and discharge to the overlying Ethan aquifer. The Codell aquifer is recharged by downward leakage from the overlying Niobrara and Floyd aquifers and upward movement from fractures in the underlying Sioux Quartzite. Natural discharge from the Codell aquifer in Davison County is by subsurface flow to outcrops along Firesteel Creek, to Lake Mitchell, and to the James River.

Yankton County

The Lower James-Missouri aquifer is the major glacial outwash aquifer in Yankton County, underlying almost 50 percent of the county. Recharge is from seepage from streams and infiltration by precipitation. It is estimated that the southern part of the aquifer receives about 15,000 acre-feet of annual recharge from the Missouri River (E. F. Bugliosi, U.S. Geological Survey, written commun., 1982). In the northern part, the aquifer is thought to receive significant recharge by leakage from streams. Both recharge and discharge areas appear to be located along Beaver Creek where the alluvium of the stream is in contact with the underlying outwash (E. F. Bugliosi, written commun., 1982). There may also be areas along the upper reaches of the James River in Yankton County that discharge water to the underlying aquifer (E. F. Bugliosi, written commun., 1982). Discharge from the aquifer is mostly subsurface although about 4,800 acre-feet annually discharges to the Missouri River in one area.

Conclusions

Review of water-resources studies made on all but two counties transversed by the James River in South Dakota indicates that there is not significant hydraulic connection between the James River and underlying aquifers in Brown, Beadle, and Sanborn Counties. Some interchange may occur in Hanson, Davison, and Yankton Counties, although this interchange has not been quantified. The water-resource study for Spink County is scheduled to begin in 1985 and the study for Hutchinson County is scheduled to begin in 1983.

ANALYSIS OF SAND LAKE NATIONAL WILDLIFE REFUGE

Sand Lake National Wildlife Refuge (fig. 19) was established by Congress in 1935 to preserve habitat for nesting and migrating waterfowl. Included within the 21,451 acres of refuge are Sand Lake (capacity = 18,000 acre-feet, and surface area = 6,050 acres at spillway elevation 1,287.52 feet above NGVD of 1929) and Mud Lake (capacity = 6,600 acre-feet, and surface area = 4,950 acres at spillway elevation 1,288.23 feet above NGVD of 1929). Due to the shallow characteristics of both lakes, extensive stands of phragmites, cattail, and bulrush are interspersed with the open water of both lakes.

Water Budget

Procedure

A mass-balance computation was made on the refuge using U.S. Fish and Wildlife Service operating records, Bureau of Reclamation area-capacity data, and evaporation/precipitation data developed by the Geological Survey as a part of this study. These items are discussed in the following sections.

Operating Records

The Fish and Wildlife Service has maintained monthly operating records on both lakes since 1969. The operation records, tabulated in table 21 (Supplemental Information section at back of report), consist of average monthly lake elevations and associated capacities and surface areas for each lake. Maximum monthly lake elevations were recorded for the entire period of record, and minimum monthly lake elevations have been recorded since 1977.

Area-Capacity Data

The area-capacity records maintained by Fish and Wildlife Service during 1969-81 are based on Fish and Wildlife Service area-capacity data, which are based on a 1935 topographic map and a 1946 survey. The Bureau of Reclamation measured cross sections of the lakes during the winter of 1979-80 and developed new area-capacity curves for each lake in 1981. Copies of the unpublished area-capacity curves were obtained from the Bureau and are presented as figures 20 and 21.

As a part of this study, the Fish and Wildlife Service operation records were used in conjunction with the Bureau area-capacity curves to adjust the monthly values for lake contents and surface areas for the record period (1969-81). These data are presented in tables 22 through 25 (Supplemental Information section at back of report).

The monthly combined change in storage for the lakes was computed and then accumulated for the 13 years of record from 1969 to 1981. The plot of these data are compared to the cumulative net gains and losses for the James River between LaMoure, N. Dak., and Columbia, S. Dak., in figure 22. The figure indicates that a net gain on the James River commonly is associated with a net loss in storage in Sand and Mud Lakes and vice versa.

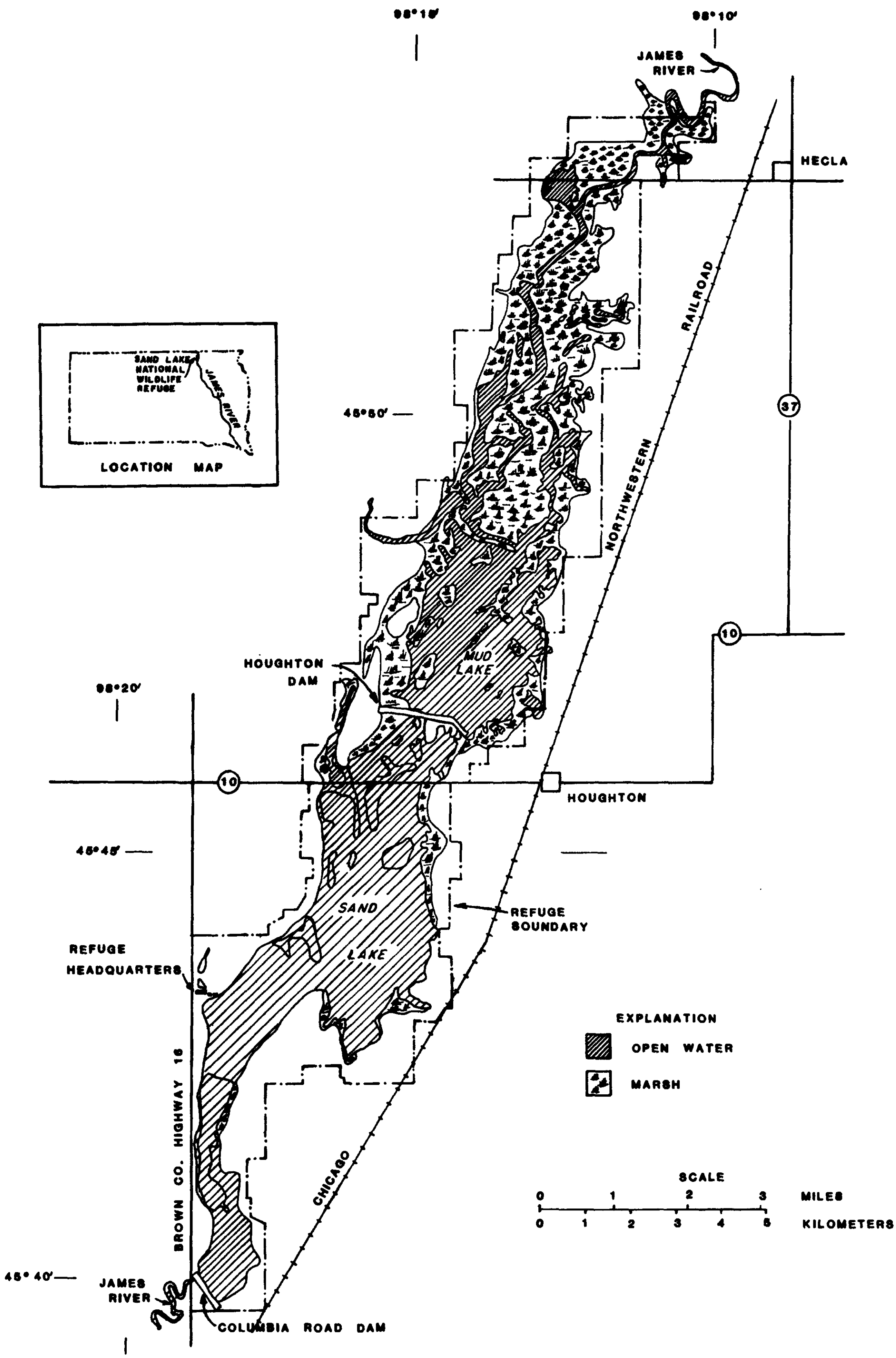
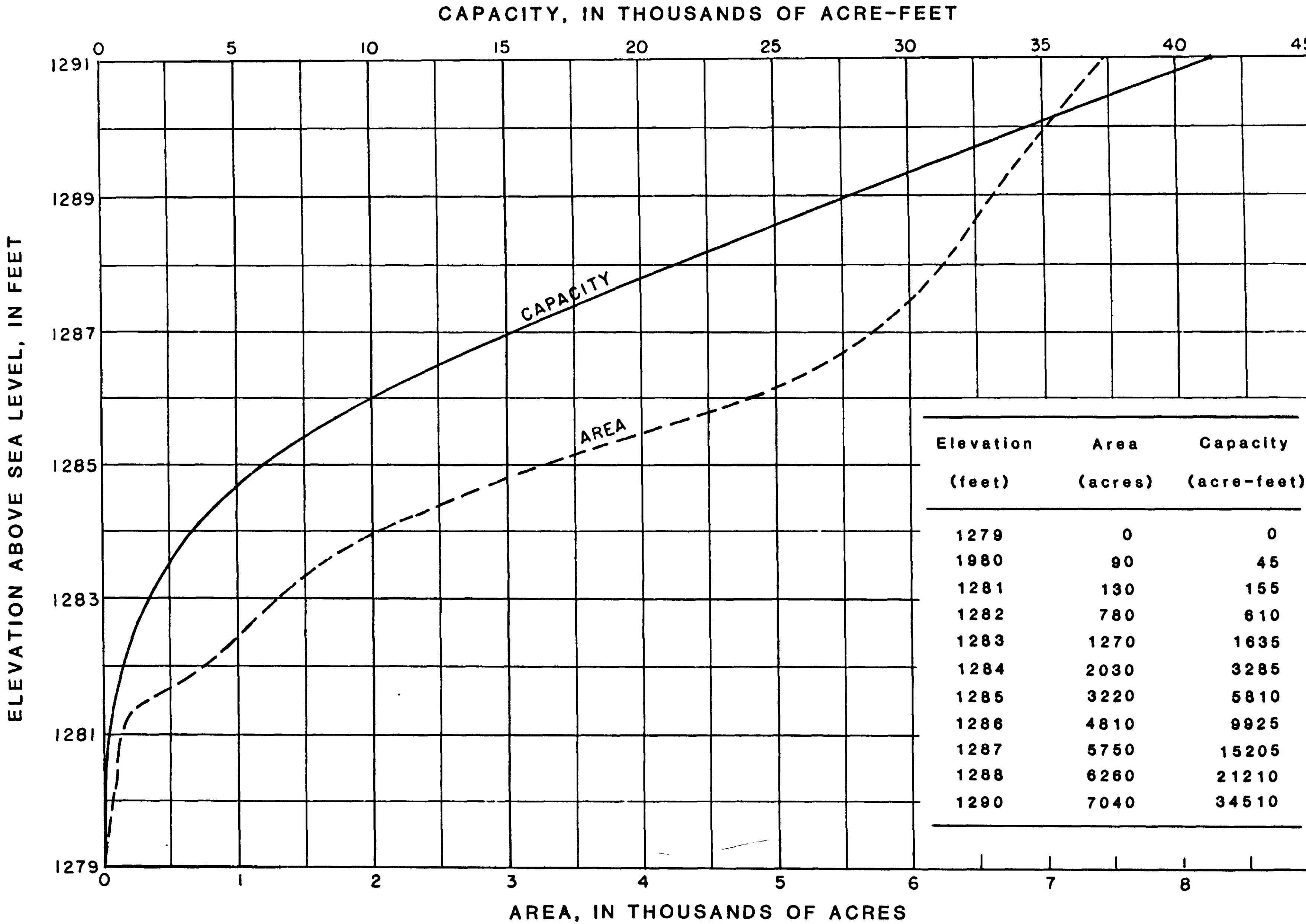
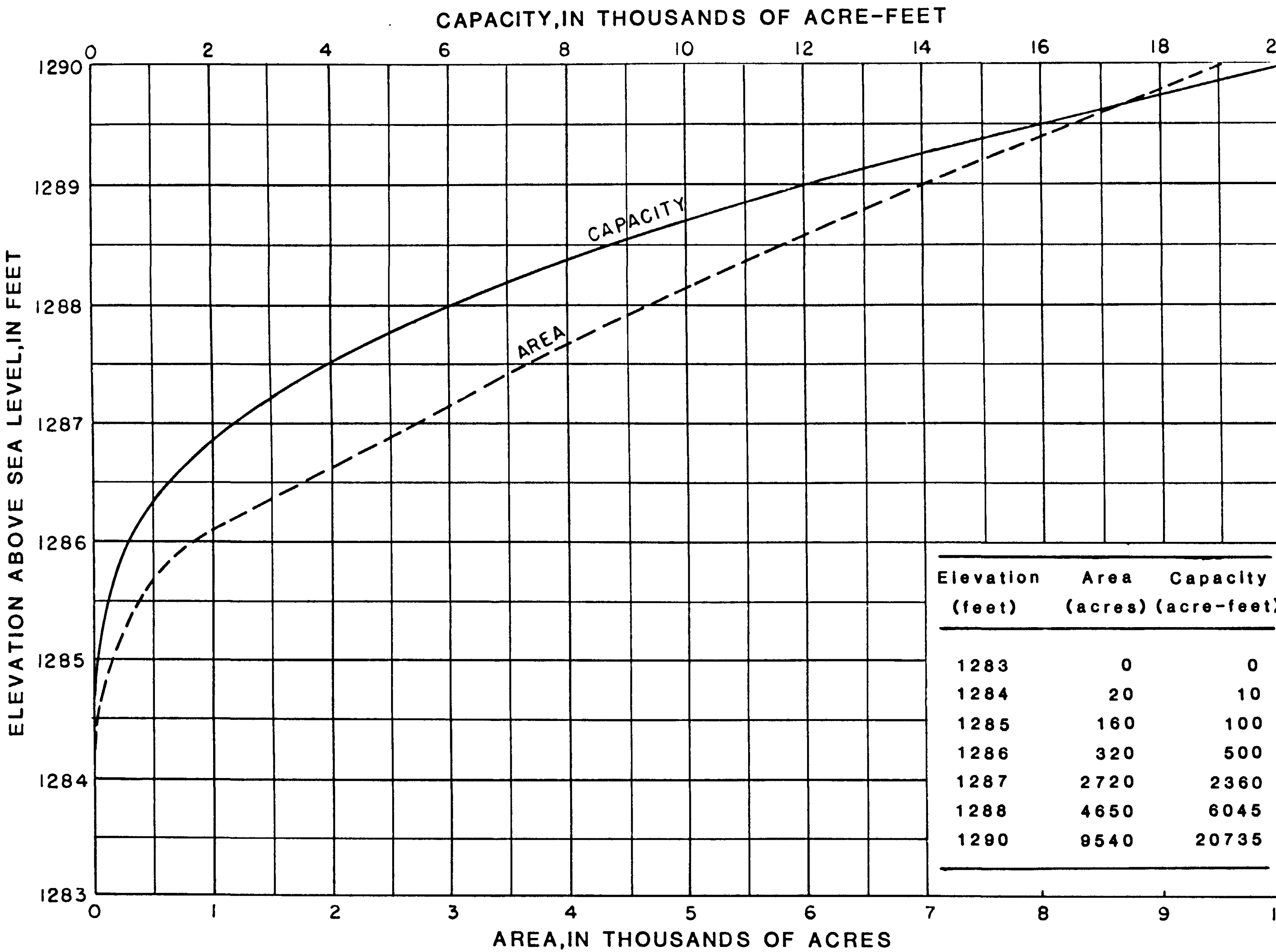


Figure 19.—Sand Lake National Wildlife Refuge (from U.S. Fish and Wildlife Service).



Elevation (feet)	Area (acres)	Capacity (acre-feet)
1279	0	0
1980	90	45
1281	130	155
1282	780	610
1283	1270	1635
1284	2030	3285
1285	3220	5810
1286	4810	9925
1287	5750	15205
1288	6260	21210
1290	7040	34510

Figure 20.--Area-capacity curve for Sand Lake (U.S. Bureau of Reclamation, written commun., 1981).



Elevation (feet)	Area (acres)	Capacity (acre-feet)
1283	0	0
1284	20	10
1285	160	100
1286	320	500
1287	2720	2360
1288	4650	6045
1290	9540	20735

Figure 21.--Area-capacity curve for Mud Lake (U.S. Bureau of Reclamation, written commun., 1981).

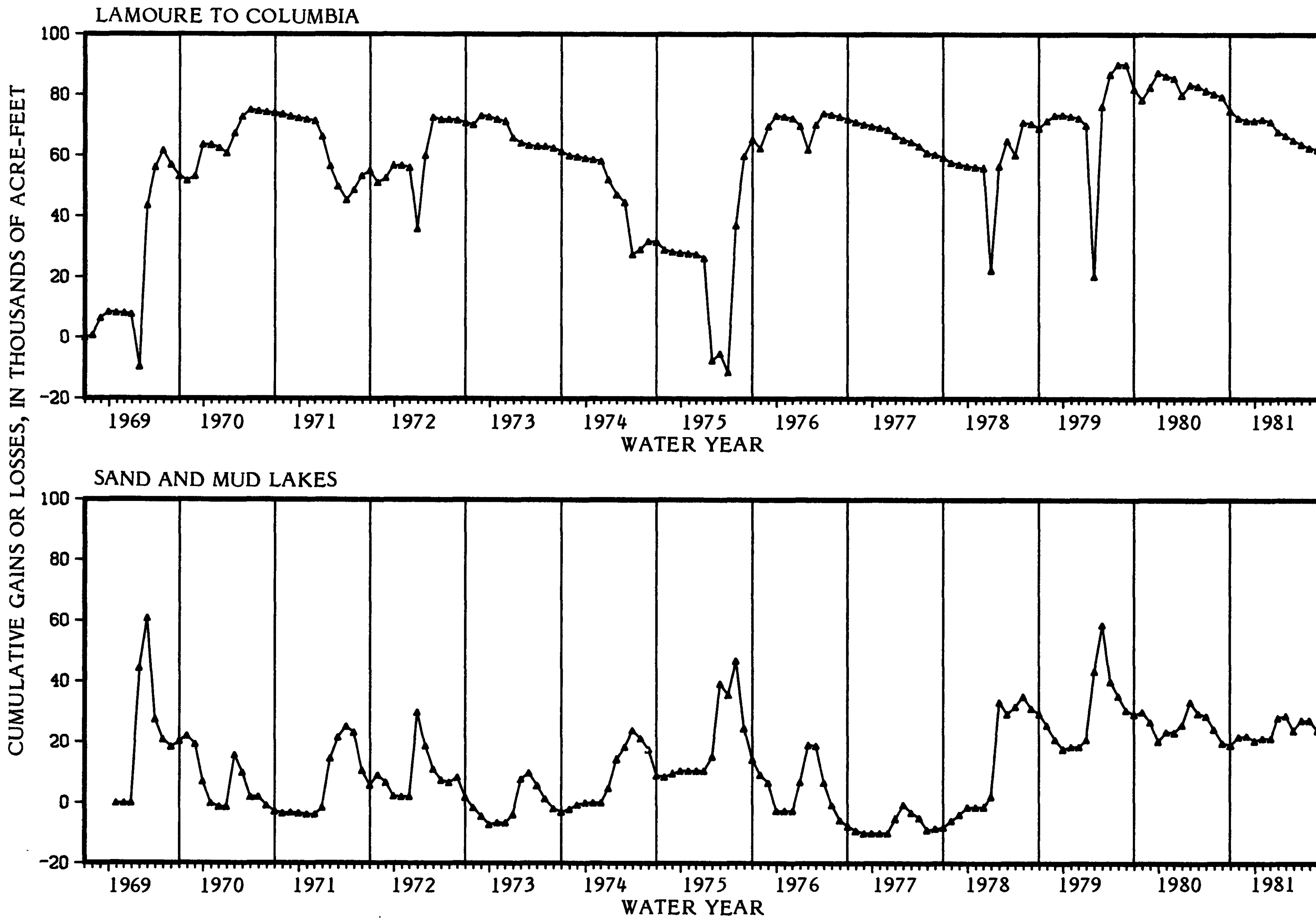


Figure 22.--Cumulative gains and losses for the James River between LaMoure, N. Dak., and Columbia, S. Dak., and cumulative change in storage for Sand and Mud Lakes, water years 1969-81.

Precipitation

Monthly precipitation data are collected by Fish and Wildlife Service at the Refuge Headquarters and published as Station Columbia 8N by the National Oceanic and Atmospheric Administration. The monthly precipitation data for water year 1969 through water year 1981 are presented in table 9. The average water-year precipitation at the Columbia station during the 13 years of record was 18.36 inches.

The National Oceanic and Atmospheric Administration does not publish the normal precipitation for the Columbia station. Therefore, it is not possible to compare the precipitation received at the Refuge during water years 1969-81 to the long-term normal. This comparison is possible for the station at Britton which is located about 22 miles east of Mud Lake (table 10). During water years 1969-81, annual precipitation received at Britton averaged 16.66 inches, which is 2.69 inches per year less than the 30-year normal from 1941 to 1970. A plot of the cumulative departure from normal precipitation at Britton during water years 1969-81 is presented in figure 23. Precipitation at the Refuge averaged 1.70 inches more than at Britton during water years 1969-81.

Evaporation

The National Oceanic and Atmospheric Administration has maintained an evaporation pan at Station Redfield 6E since August 1949. The average pan evaporation and gross reservoir evaporation (0.7 times pan evaporation) for April through November (1949-81) are as follows:

Month	Average pan evaporation (inches)1/	Gross reservoir evaporation (inches)
April	5.22	3.65
May	7.48	5.24
June	8.00	5.60
July	9.02	6.31
August	8.08	5.66
September	5.86	4.10
October	4.04	2.83
November	1.15	.81
Total	48.85	34.20

1/ Computed by W. F. Lytle, Agricultural Engineering Department, South Dakota State University, written commun., 1982.

Table 9.—Precipitation at Sand Lake National Wildlife Refuge (Station Columbia 8N) during water years 1969-81, in inches (T = trace)

Year	Month												
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Total
1969	0.48	0.78	2.04	1.54	2.60	0.25	0.89	2.34	3.34	3.76	0.99	0.44	19.45
1970	.51	.13	1.15	1.00	.84	2.59	3.66	2.33	1.91	3.11	.25	1.12	18.60
1971	1.25	2.39	.59	.98	.40	.07	1.45	2.62	3.84	1.72	1.27	1.32	17.90
1972	3.01	1.57	.97	1.27	.77	1.40	.89	5.99	1.32	4.16	1.08	T	22.43
1973	1.26	.73	1.20	.30	.07	1.49	.99	1.59	1.91	1.56	1.88	4.45	17.43
1974	2.09	.44	.73	.01	.45	.59	2.67	5.55	.17	1.56	1.53	.37	16.16
1975	.50	.02	.02*	.56	.29	2.57	3.28*	1.93	6.63	.58	2.74	1.73	20.85
1976	1.25	.22	.36	1.03	.58	.84	1.46	.45*	2.95	.25	.99	.80	11.18
1977	.21	.02	.22	.24*	.67	3.33	.85	3.14	2.33	2.68	2.72	4.34	20.75
1978	1.44	2.03	.86*	.01	.37	.73	2.00	3.44	7.04	1.67	3.29	T	22.88
1979	.21	.58	T	1.22	1.25	1.57	2.49	2.15	4.05	3.11	.61	.41	17.65
1980	1.11	.04	.13	.72	.42	.54	.58	2.52	2.40	1.08	4.71	1.03	15.28
1981	1.30	T	.04	.16	.10	.78	1.21	1.71	3.19	5.69	2.78	1.18	18.14
Average	1.12	.69	.64	.70	.68	1.29	1.72	2.75	3.16	2.38	1.91	1.32	18.36

*Denotes estimated values.

Table 10.--Precipitation at Britton, S. Dak., during water years 1969-81, in inches (T = trace)

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Total
1969	1.43	0.49	1.27	1.05	0.81	0.31	1.89	3.71	1.58	2.54	0.10	0.23	15.41
1970	1.76	.25	.85	.04	.26	.29	1.25	2.09	4.15	2.00	.27	2.11	15.32
1971	1.12	2.00	.17	.75	.36	.17	1.37	2.47	4.92	2.12	2.09	1.11	18.65
1972	3.24	1.79	.56	.76	.89	.59	.63	6.74	.58	5.32	1.03	.16	22.29
1973	.83	.23	1.44	.27	.19	1.06	1.45	3.14	1.43	2.03	2.83	2.67	17.57
1974	1.21	.95	.34	T	.39	.34	1.32	4.80	.70	1.41*	1.90	.23	13.59
1975	.45	.06	T	.94	.28	.93	3.61	2.36	5.51	T	1.64	1.66	17.44
1976	1.32	.18	.23	.66	.40	.56	1.23	.36	3.43	1.10	.52	.68	10.67
1977	.18	.03	.28	.48	.80	2.36	1.16	2.03	2.52	2.36	3.33	4.13	19.66
1978	1.20	2.05	.72	.35	.32	.51	1.78	2.60	7.07	2.64	1.74	.56	21.54
1979	.48	.52	.02	.67	.82	1.61	1.87	1.40	2.74	2.17	1.37	.14	13.81
1980	1.80	.42	.17	.52	.44	.58	.60	1.72	2.80	.74	4.05	1.11	14.95
1981	1.63	T	.09	.19	.30	1.16	.71	1.10	4.89	2.37	2.46	.82	15.72
Average	1.28	.69	.47	.51	.48	.81	1.45	2.66	3.26	2.06	1.79	1.20	16.66
Normal	1.15	.62	.41	.34	.45	.57	1.88	2.59	4.28	2.71	2.46	1.89	19.35

*Denotes estimated value.

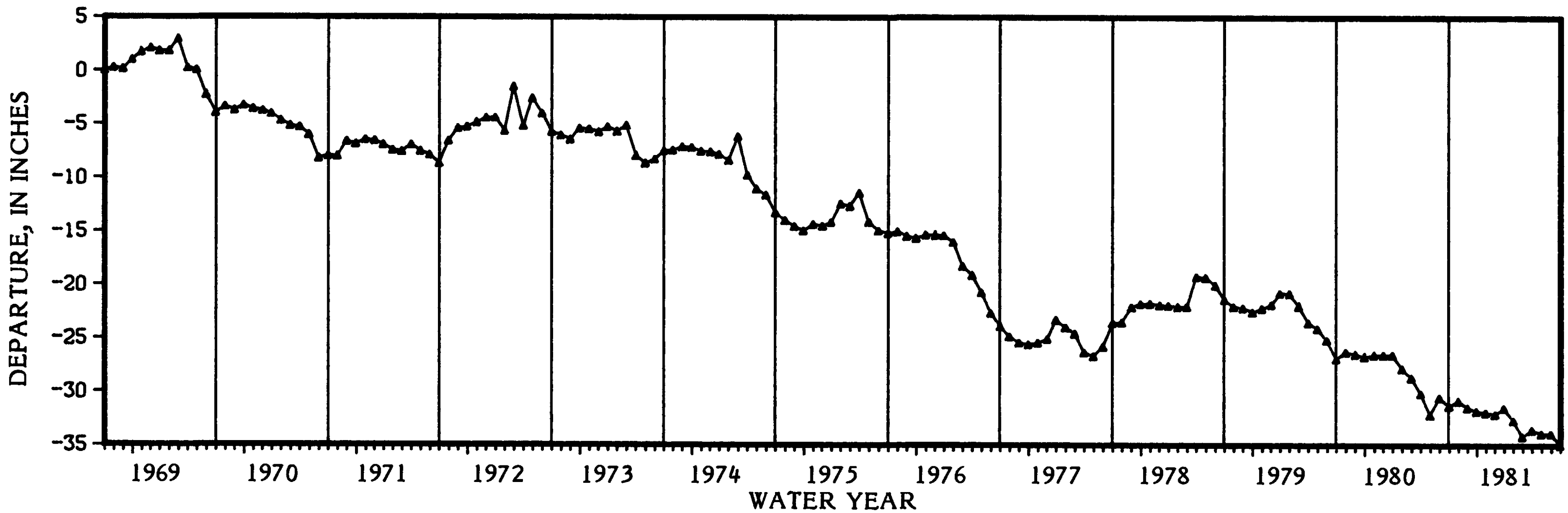


Figure 23.--Cumulative departure from normal precipitation (in inches) for Britton, S. Dak., during water years 1969-81.

The factor of 0.7 to convert pan evaporation to gross reservoir evaporation is intended for use in converting annual values and needs to be used with caution when converting monthly values (Winter, 1981). However, due to the lack of better data, this estimation was used. Evaporation during December through March was assumed to be negligible for the current study.

The above evaporation data were used in conjunction with the Bureau of Reclamation area-capacity curves (figs. 20 and 21) to develop gross reservoir-evaporation curves for Sand and Mud Lakes (figs. 24 and 25).

Discussion

The mass-balance computation was made as follows on the reach between LaMoure, N. Dak., and Columbia, S. Dak., for water years 1969-81 using streamflow at LaMoure and Columbia, operating records for Sand and Mud Lakes, and the evaporation and precipitation data previously discussed.

Cumulative historic streamflow at LaMoure during water years 1969-81 was 1,050,000 acre-feet. The cumulative streamflow at Columbia during the same 13 water years was 1,109,000 acre-feet. This indicates a net stream gain in the reach during the 13 years of record. The contributing drainage area upstream from LaMoure is about 1,790 square miles and upstream from Columbia it is about 4,050 square miles. The net stream gain can be attributed to intervening inflows from the 2,260 square miles of contributing drainage area between LaMoure and Columbia. Although the flows measured at the Columbia gaging station probably approximate outflows from the refuge, data are not available for inflows to the refuge. An estimate of refuge inflows was made by increasing the LaMoure flows by the ratio of the square roots of the contributing drainage area upstream from the State line (3,850 square miles) and the contributing drainage area upstream from LaMoure. This ratio equals 1.47, resulting in a theoretical refuge inflow of 1,543,000 acre-feet during the 13 years of record. Subtracting the measured flow at Columbia from this figure, total losses in the refuge during the 13 years of record are estimated to be 434,000 acre-feet.

Using monthly contents from the operating records, estimates of monthly evaporation from each lake were made using the evaporation curves (figs. 23 and 24). Total gross evaporation from Sand Lake during the 13 years (water years 1969-81) was estimated to be 197,200 acre-feet and gross evaporation from Mud Lake was estimated to be 182,400 acre-feet, for a total of 379,600 acre-feet. The precipitation data for Columbia were used in conjunction with the monthly surface-area data from the operating records to estimate monthly precipitation additions to each lake during the months of evaporation losses. It is estimated that precipitation added 98,800 acre-feet to Sand Lake and 95,700 acre-feet to Mud Lake during the 13 years. When evaporation and precipitation additions are considered together, a net loss of 185,100 acre-feet is indicated.

Subtracting the 185,100 acre-feet net loss from the theoretical refuge inflow (1,543,000 acre-feet) results in a theoretical refuge outflow of 1,357,900 acre-feet. This compares to measured flow of 1,109,000 acre-feet at Columbia which indicates 248,900 acre-feet of unaccounted-for losses during the 13 years of record, or about 19,150 acre-feet per year. The average April-November surface area of the two lakes during the 13 years of record was about 9,800 acres, resulting in unaccounted-for losses of 1.95 acre-feet per acre per year.

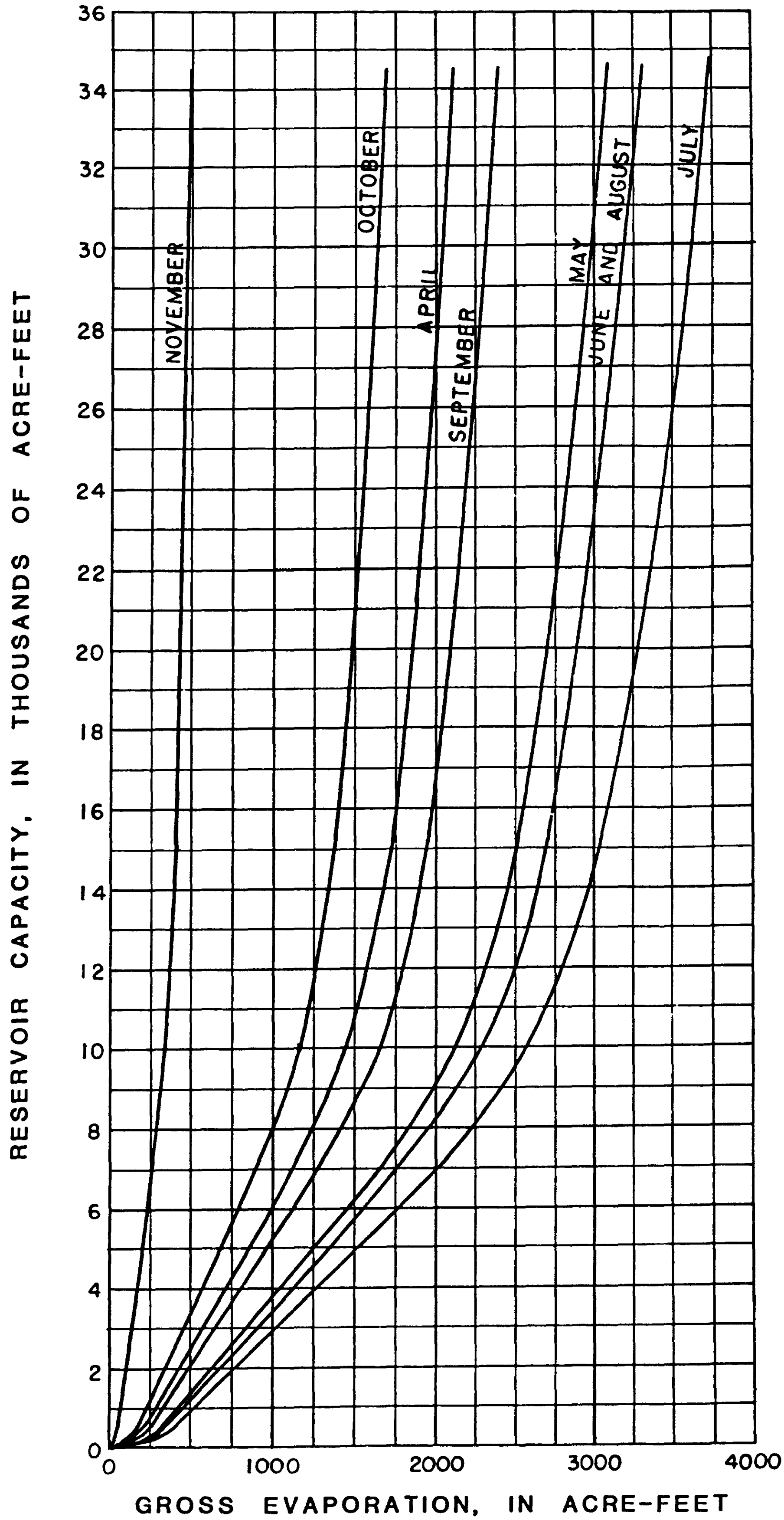


Figure 24.--Gross reservoir-evaporation curves for Sand Lake.

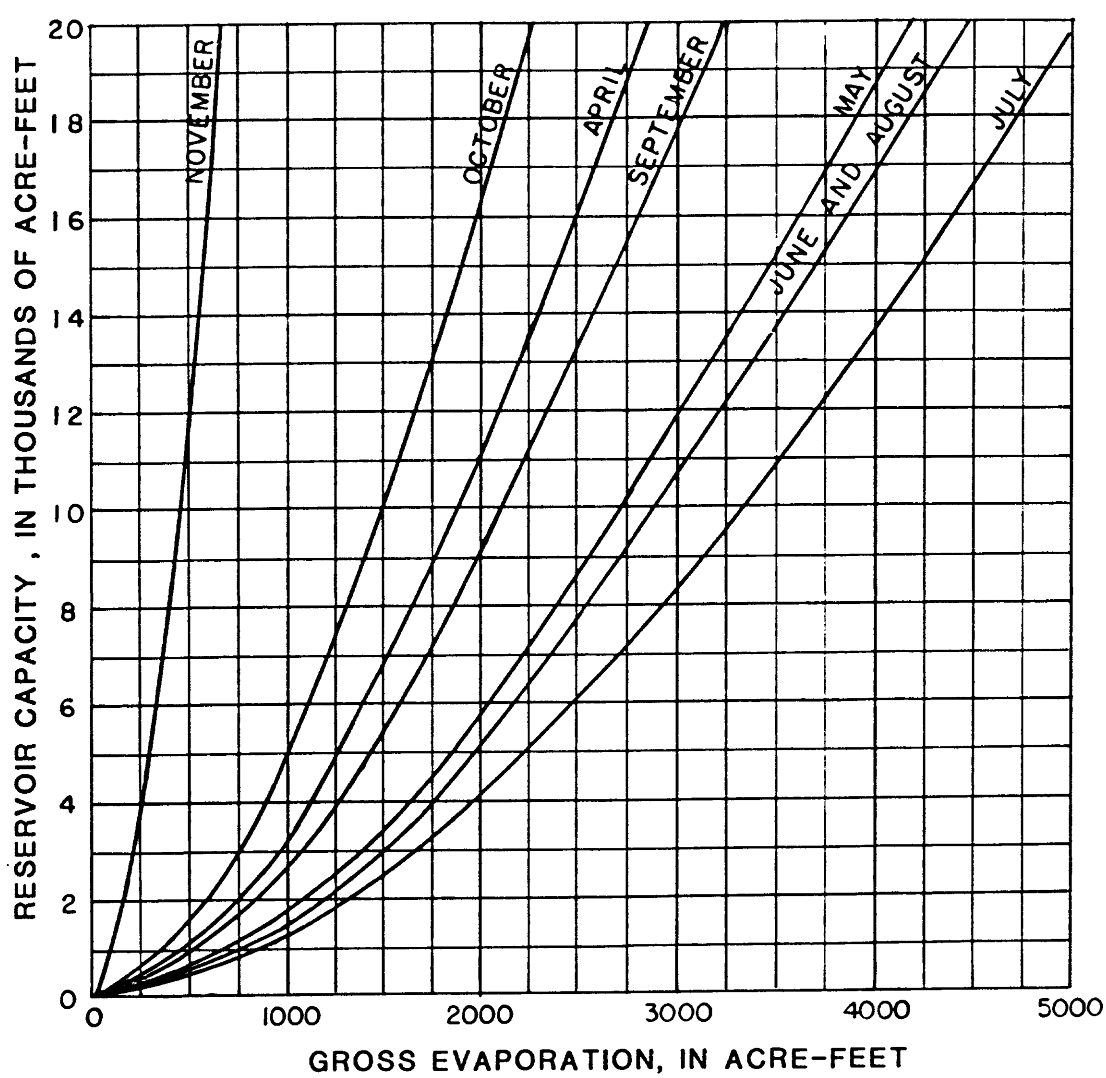


Figure 25.--Gross reservoir-evaporation curves for Mud Lake.

Conclusions

Transpiration by the extensive vegetative growth (phragmites, cattail, and bulrush) in the lakes during each growing season may be the reason for an unaccounted-for loss of 1.95 acre-feet per acre from Sand and Mud Lakes. In addition, the refuge manager indicated his belief, as well as the belief of some local landowners, that there is some lake loss to the water table on the east side of the lakes (this item was discussed in further detail in the section on Ground Water-Surface Water Relationships).

In addition, the method of estimation of theoretical refuge inflows may have introduced significant error into the estimate of unaccounted-for losses. Considering the physical characteristics of the James River between LaMoure and the State line, the drainage-area method of extending the LaMoure flows to the State line could likely over-estimate theoretical refuge inflows, which in turn would result in an over-estimation of unaccounted-for losses. For instance, decreasing inflow to 90 percent of the previously-computed theoretical refuge inflow gives a 13-year inflow of 1,389,000 acre-feet. This decreases the unaccounted-for losses to 94,600 acre-feet, or 0.74 acre-feet per acre per year.

Due to the shallow characteristics of Sand and Mud Lakes, it is possible that the lake evaporation is more than 70 percent of pan evaporation. If lake evaporation is increased by 10 percent, along with decreasing inflows similar to above, the unaccounted-for losses become 56,900 acre-feet, or 0.45 acre-feet per acre per year.

This points out that a relatively small error (10 percent) in estimation of refuge inflows or evaporation produces a significantly different estimation of unaccounted-for losses.

Water Quality

Procedure

As a part of the studies on Sand Lake National Wildlife Refuge, water-quality samples were collected along selected cross sections (fig. 26) on Sand and Mud Lakes on July 19-21, 1982. Onsite measurements of pH, temperature, dissolved oxygen, and specific conductance were made and the samples that were collected were mailed to the U.S. Geological Survey laboratory at Arvada, Colorado.

Equipment

Measurements of dissolved oxygen were made along each cross section utilizing a YSI (Yellow Springs Instrument) Model 54 oxygen meter[1/] and measurements of specific conductance were made using an Electronic Instruments Limited Model MC-1, MARK V conductance meter. A Brooklyn P-M laboratory-type thermometer (accurate to the nearest 0.1°C) was used to check the thermistor readings on the dissolved-oxygen meter. Individual samples collected along each cross section were composited into one sample (using the U.S. Geological Survey churn splitter) representing the particular cross section for common constituent and pesticide analyses. An Orion Research Ionalyzer Model 407A pH meter was used to measure the pH of the composited samples for each cross section. A YSI Model 56 dissolved-oxygen monitor was installed first in Sand Lake and then in Mud Lake to monitor dissolved oxygen for 24 hours in each lake (monitor locations are indicated in fig. 26).

[1/] The use of brand names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

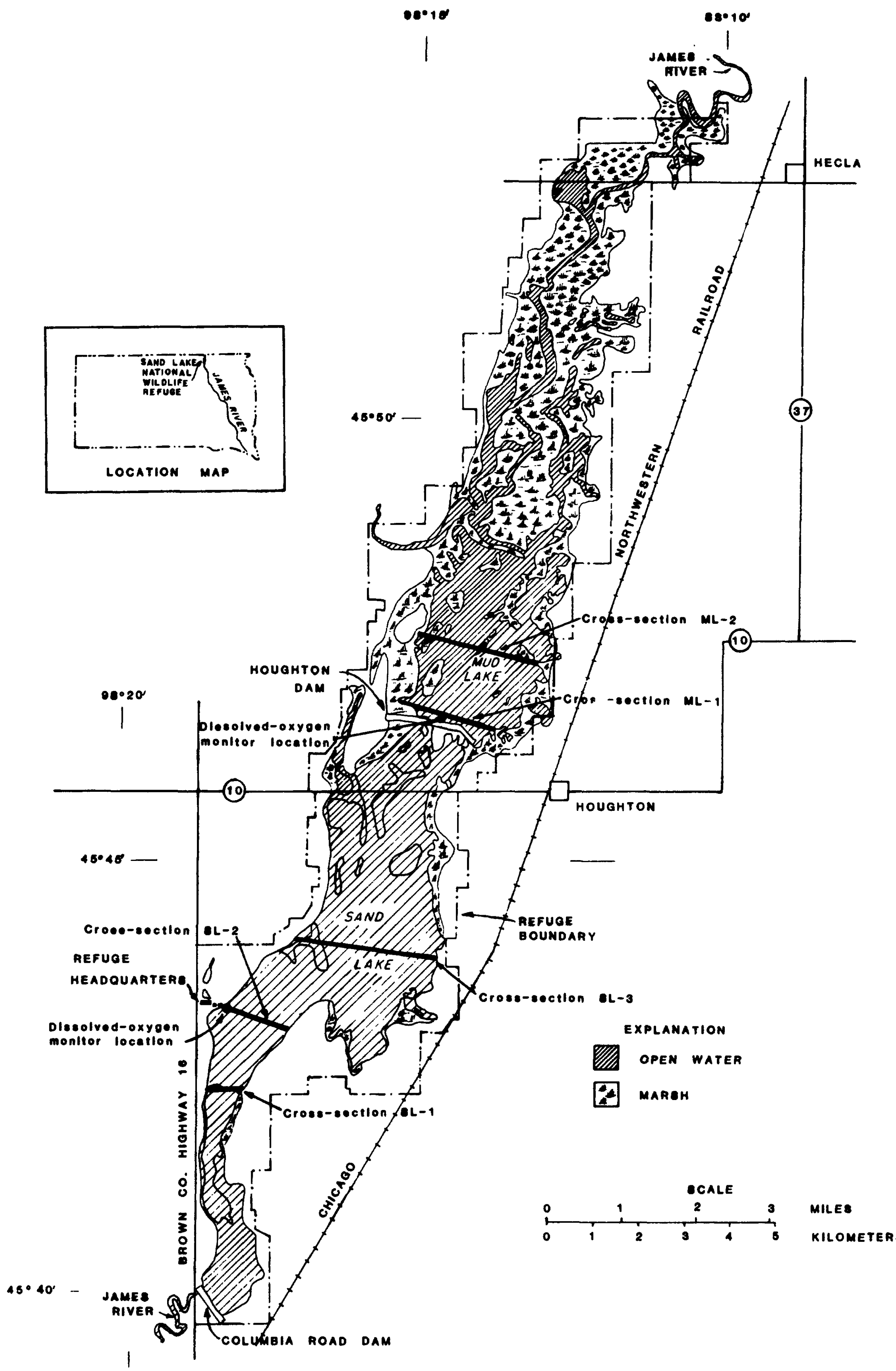


Figure 26.—Location of water-quality sampling points and cross sections on Sand and Mud Lakes.

Sample preparation

After pH and specific conductance were measured, five 250-mL (milliliter) splits were prepared from each composited cross-sectional sample in plastic bottles obtained from the laboratory. The first two splits were drawn out of the churn splitter (while churning) and both bottles were labeled Ru (raw untreated) for measurement of pH, specific conductance, and alkalinity in the laboratory.

The next three splits were filtered from the churn splitter (while churning) using a peristaltic pump connected to a filter holder clamping a membrane filter 142 mm (millimeters) in diameter and 0.45 µm (micrometer) in pore size. The first bottle was labeled Fu (filtered untreated) for measurement of sulfate, chloride, fluoride, and silica. The second bottle, acid rinsed by the laboratory, was labeled Fa (filtered acidified) for measurement of calcium, magnesium, sodium, potassium, and boron. This bottle was treated with 1 mL of triple distilled nitric acid supplied by the laboratory. The last bottle was labeled Fc (filtered chilled) for measurement of nitrate plus nitrite as nitrogen and both total and dissolved phosphorous as phosphorous. The last split was prepared in a non light-sensitive bottle (brown) to which was added a sodium chloride tablet containing 10 mg (milligrams) mercuric chloride for nutrient preservation. The brown bottles and mercuric chloride preservatives were supplied by the laboratory. Each brown bottle was immediately placed in a portable refrigerator for cooling and later iced for shipment to the laboratory.

The pesticide samples were not taken out of the churn splitter but instead were composited by adding equal volumes of water at each vertical to a 1-L (liter) narrow-mouthed glass bottle supplied by the laboratory. Four bottles were necessary to collect enough water for analysis of carbamate, chlorophenoxy acid, or ganochlorine, or ganophosphorous, and triazine pesticide compounds.

The three Sand Lake sample splits plus the pesticide samples were mailed to the laboratory the next morning after collection and preparation. The two Mud Lake splits and pesticide samples were mailed the same day.

Discussion of Onsite Measurements

The onsite measurements of pH, temperature, dissolved oxygen, and specific conductance are summarized in table 11. Within Sand Lake, the pH of the composited samples ranged from 8.7 to 9.2, temperature ranged from 24.0 to 27.5°C, dissolved oxygen ranged from 7.3 to 14.2 mg/L (milligrams per liter), and specific conductance ranged from 760 to 805 µmhos/cm (micromhos per centimeter at 25°C). Within Mud Lake, the pH of both composited samples was 8.9, temperature ranged from 21.0 to 23.5°C, dissolved oxygen ranged from 6.4 to 14.2 mg/L, and specific conductance ranged from 645 to 720 µmhos/cm.

The measured dissolved-oxygen concentrations in Sand and Mud Lakes are compared with the dissolved-oxygen saturation curve for water at 725 mm pressure (the measured pressure on the days the measurements were taken) in figure 27. Seven of the 10 dissolved-oxygen measurements in Sand Lake indicate supersaturation and the other three samples are within 1 mg/L of the saturation level. Within Mud Lake, concentrations in all but one of the six samples were less than the dissolved-oxygen saturation level. The Mud Lake sample that was greater than the saturation level (center of cross-section 2) was collected near an area of extensive underwater vegetation, which may account for the large dissolved-oxygen level.

Table 11.--Summary of onsite measurements for selected water-quality properties and constituents (Sand and Mud Lakes)

Cross section	Sampling date	Sampling time	pH of composite sample	Water temperature (degrees Celsius)	Dissolved oxygen (milligrams per liter)	Specific conductance (micromhos per centimeter at 25° Celsius)
S.L.-1	7-20-82					
Right[1/]		9:35 a.m.	9.2	25.0	12.8	760
Right		9:50 a.m.		25.0	14.2	790
Center		10:10 a.m.		24.0	9.7	800
Left		10:15 a.m.		24.0	8.9	790
S.L.-2	7-20-82					
Right		11:45 a.m.	8.7	24.0	8.9	760
Center		12:00 m.		24.0	7.3	805
Left		12:10 p.m.		24.0	7.7	795
S.L.-3	7-20-82					
Right		4:00 p.m.	8.9	27.5	11.8	800
Center		4:15 p.m.		25.5	7.8	800
Left		4:25 p.m.		25.0	7.6	790
M.L.-1	7-21-82					
Right		10:25 a.m.	8.9	22.0	7.3	720
Center		10:45 a.m.		23.0	6.6	720
Left		10:55 a.m.		23.5	6.9	720
M.L.-2	7-21-82					
Right		12:10 p.m.	8.9	21.0	6.4	645
Center		12:20 p.m.		22.5	14.2	680
Left		12:30 p.m.		23.0	6.8	660

1/ Designation of bank (right bank looking in downstream direction).

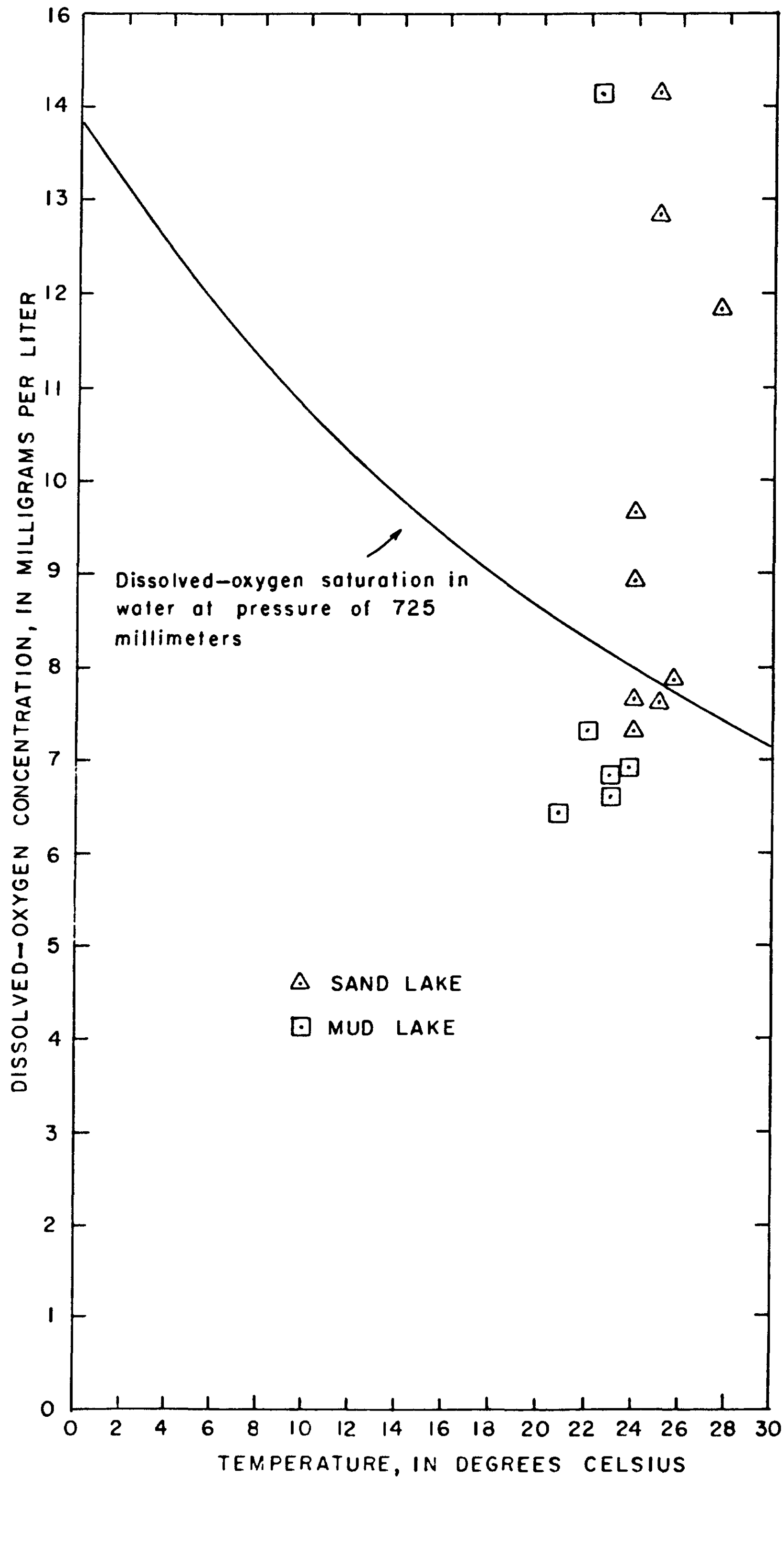


Figure 27.--Dissolved-oxygen concentration of water samples from Sand and Mud Lakes (July 20-21, 1982).

An intense thunderstorm, with accompanying high winds, passed through the area the evening of July 20 which was subsequent to the sampling of Sand Lake but prior to the sampling of Mud Lake. Fish and Wildlife Service personnel indicate that 1.61 inches of rain was measured at the Refuge Headquarters. The lower water temperatures measured in Mud Lake on July 21 may be due to the rainfall and the mixing action resulting from the high winds. The smaller dissolved-oxygen concentrations may have resulted from the lack of sunlight and mixing action by the wind or the escape of dissolved oxygen from the supersaturated lake water during the low-pressure period that probably accompanied the storm.

A plot of the dissolved-oxygen concentrations measured in Sand Lake between 2:10 p.m. on July 19 and 2:10 p.m. on July 20 is presented in figure 28. A monitor malfunction subsequent to initial setup was not discovered until about 8:00 p.m. Dissolved-oxygen concentrations during this period were estimated as a straight line connection between the initial dissolved-oxygen concentration (9.6 mg/L at 2:10 p.m.) and the dissolved-oxygen concentration when the malfunction was discovered (11.2 mg/L at 8:00 p.m.). This estimate is shown as a dashed line in figure 28. The dissolved-oxygen concentration decreased from 11.2 mg/L at 8:10 p.m. to a minimum of 9.0 mg/L (6:10 a.m. and 7:10 a.m.) before beginning to rise to a maximum of 11.6 mg/L at 2:10 when monitoring was discontinued. The dissolved-oxygen concentrations in Sand Lake were greater than saturation for the entire 24 hours (fig. 28). This supersaturation condition, plus the trend of increasing dissolved-oxygen concentrations during the day-light hours and decreasing dissolved-oxygen concentrations during the night-time hours indicates significant photosynthetic activity in Sand Lake.

A plot of the dissolved-oxygen concentrations measured in Mud Lake between 3:20 p.m. on July 20 and 2:20 p.m. on July 21 is presented in figure 29. The dissolved-oxygen concentrations between initial set-up and midnight show some irregularity which probably can be attributed to the storm activity which occurred during the evening. From midnight to about 7:00 a.m., the dissolved-oxygen concentration decreased from 7.9 mg/L to 6.2 mg/L before beginning an increasing trend to a maximum dissolved-oxygen concentration of 11.6 mg/L when the monitor was removed. The dissolved-oxygen concentrations generally were less than saturation until about 11:00 a.m. on July 20. The trend shown by the data in figure 29 also indicates photosynthetic activity in Mud Lake during the monitoring.

Discussion of Laboratory Analyses

Common Constituents

Analyses of common constituents were made to ascertain the general characteristics of the lake waters and to determine if there was any concentrating effect as flows travel through the lake system. This concentrating effect would be expected to occur as a result of lake evaporation and transpiration by lake vegetation. Normally, the concentrating effect would be expected to be greatest during the summer months and when lake inflows are minimal.

The results of the common constituent analyses for the three samples from Sand Lake and the two samples from Mud Lake are presented in table 12. The analyses indicate moderate concentrations of all constituents and that the water generally was a calcium and magnesium bicarbonate type with lesser concentrations of sodium sulfate and chloride.

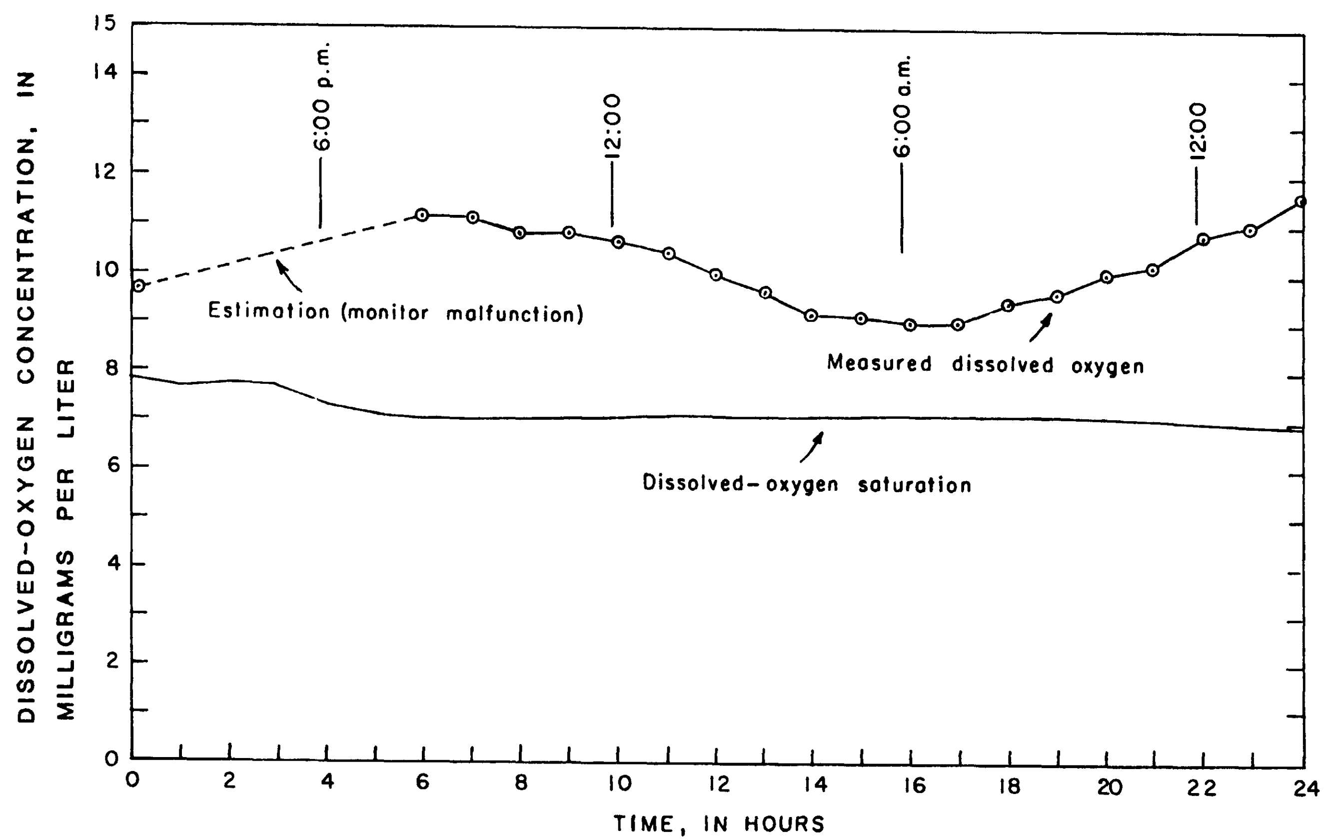


Figure 28.--Dissolved-oxygen concentrations measured at one point in Sand Lake for 24 hours on July 19-20, 1982.

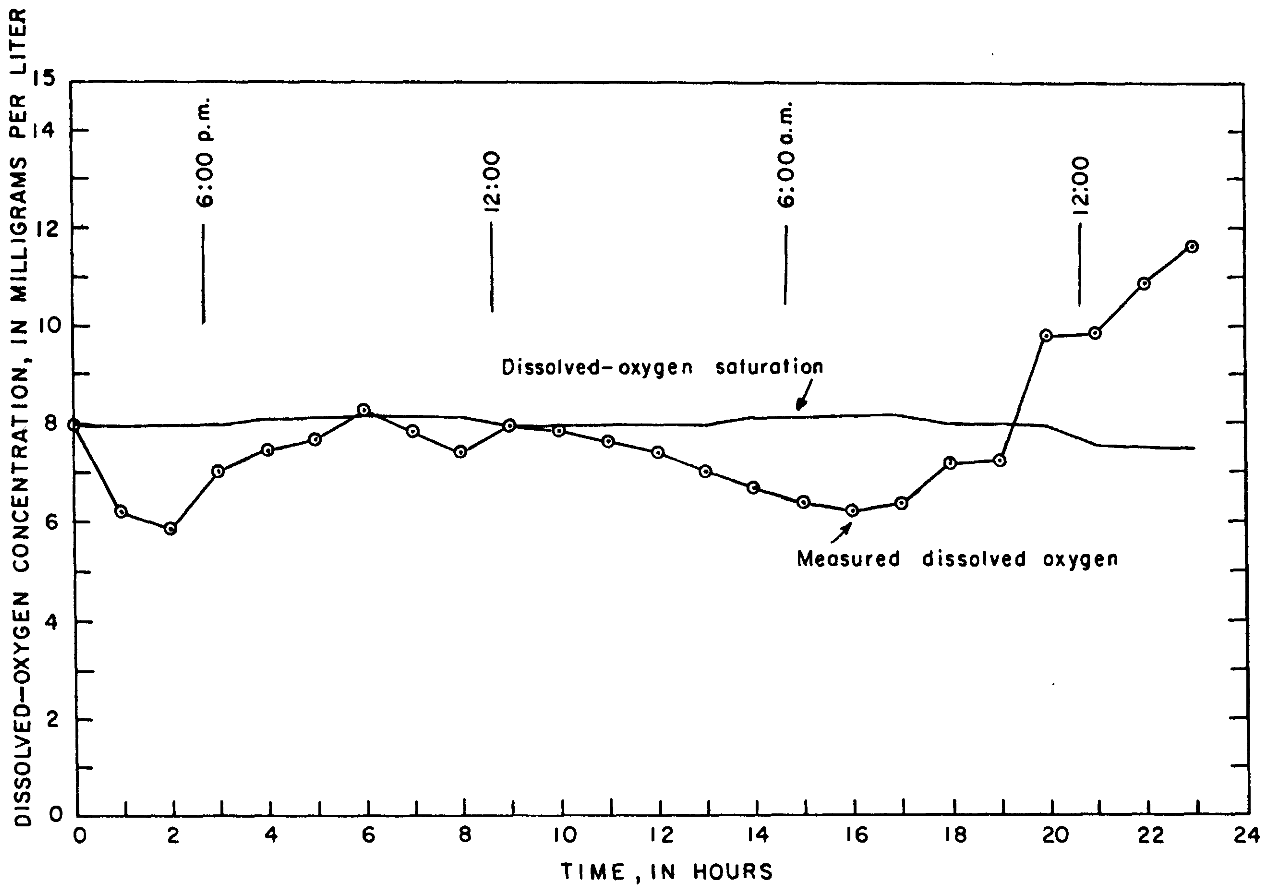


Figure 29.—Dissolved-oxygen concentrations measured at one point in Mud Lake for 24 hours on July 20-21, 1982.

Table 12.—Summary of common constituent analyses of water samples from Sand and Mud Lakes (July 20 and 21, 1982)

[µmhos at 25°C = micromhos per centimeter at 25° Celsius; °C = degrees Celsius; mg/L = milligrams per liter; acre-ft = acre-feet]

	Station 454215098180700 (Sand Lake cross section 1)	Station 454310098173600 (Sand Lake cross section 2)	Station 454356098161000 (Sand Lake cross section 3)	Station 454638098143000 (Mud Lake cross section 1)	Station 454716098134500 (Mud Lake cross section 2)
Date of sample	82-07-20	82-07-20	82-07-20	82-07-21	82-07-21
Time	0900	1115	1600	1100	0100
Specific conductance (µmhos at 25°C)	790	790	790	720	680
pH	9.2	8.7	8.9	8.9	8.9
Temperature (°C)	24.5	24.0	26.0	23.0	22.0
Hardness (mg/L)	240	230	230	200	180
Calcium, dissolved (mg/L)	46	44	43	39	34
Magnesium, dissolved (mg/L)	30	30	30	25	24
Sodium, dissolved (mg/L)	68	69	68	61	54
Percent sodium	37	38	37	38	37
Sodium adsorption ratio	2.1	2.2	2.2	2.1	2.0
Potassium, dissolved (mg/L)	14	13	13	13	13
Alkalinity, lab (mg/L)	264	255	253	216	193
Sulfate, dissolved (mg/L)	86	100	100	95	99
Chloride, dissolved (mg/L)	23	24	22	19	16
Fluoride, dissolved (mg/L)	.2	.2	.2	.2	.2
Silica, dissolved (mg/L)	12	12	14	14	8.6
Dissolved solids, sum of constituents (mg/L)	439	446	443	396	365
Dissolved solids (tons per acre-ft)	.60	.61	.60	.54	.50
Nitrogen, dissolved (mg/L)	.22	<.10	.11	< .10	< .10
Phosphorus, total (mg/L)	.36	.31	.33	.41	.78
Phosphorus, dissolved (mg/L)	.28	.30	.30	.28	.16
Phosphorus, ortho, dissolved (mg/L)	.25	.25	.26	.26	.14

Dissolved-solids concentrations averaged about 443 mg/L in the samples from Sand Lake and about 381 mg/L in the samples from Mud Lake. The hardness in both lakes was quite high (233 mg/L in Sand Lake and 190 mg/L in Mud Lake). Dissolved nitrate plus nitrite (as nitrogen) and phosphorus (both total and dissolved) were present in concentrations of less than 1 mg/L. Visual observations of the water samples indicated the lack of an algal bloom. The extensive underwater and above water growth of macrophytes may possibly tend to limit algal growth.

A slight concentrating effect is indicated when comparing the analyses for the two lakes. However, no significant concentrating effect is indicated within each lake. As discussed in an earlier section of this report, the samples from Mud Lake were collected the morning following an intense thunderstorm which may have caused mixing action, thereby possibly affecting the results. In addition, the existence of considerable refuge inflow (estimated to be approximately 200 ft^3/s) would tend to decrease any concentrating effect.

Pesticide Analyses

The Agricultural Experiment Station at Oakes, N. Dak., was contacted for information on the most commonly used pesticides in the James River drainage area upstream from the State line. Experiment station personnel indicated that a multitude of compounds are used, with 2,4-D, MCPA, Atrazine, Bladex, Lasso, Treflan, Banvel, Avenge, Eptan, Sutan, and Hoelon being some of the more commonly used herbicides.

A list of individual pesticides was provided to the laboratory, which determined the general pesticide groups (triazine, carbamate, organophosphorus, and so forth) for which tests would be run. Previously, the laboratory had no methods for analyses of some of the compounds and it was necessary to first obtain suitable materials for preparation of standard solutions for these compounds. The laboratory did not test for one pesticide product, Avenge, because the laboratory did not have an analytical-detection method. Efforts to contact the company that produces Avenge to obtain an analytical-detection method were unsuccessful.

The results of the pesticide analyses on the samples from Sand and Mud Lakes are presented in table 13. A total of 52 separate compounds were tested for total recoverable concentrations. Only five compounds (2,4-D, Dicamba, Picloram, Atrazine, and DEF), all herbicides, were detected. Atrazine was detected only in Mud Lake, while the other compounds were detected in both lakes. Concentrations of 2,4-D were about twice as large in Mud Lake, whereas the concentrations of Dicamba, Picloram, and DEF virtually were equal in both lakes.

The concentrations detected, maximum of 0.1 μg/L (micrograms per liter), are not considered excessive, considering the widespread use of pesticides in present farming methods. Some of the other compounds may be present in the lakes, but concentrations were not large enough to be detected by laboratory procedures.

Table 13.--Summary of pesticide analyses of water samples from Sand and Mud Lakes (July 20 and 21, 1982)

Pesticide group/compound	Concentration (micrograms per liter)[1/]				
	Sand Lake cross sections			Mud Lake cross sections	
	1	2	3	1	2
Chlorophenoxy acid herbicides					
2,4-D	0.03	0.04	0.03	0.06	0.07
2,4-DP	<.01	<.01	<.01	<.01	<.01
2,4,5-T	<.01	<.01	<.01	<.01	<.01
Dicamba	.01	.01	.01	.01	.01
Hoelon	<.01	<.01	<.01	<.01	<.01
MCPA	< 1	< 1.5	< 1	< 2	< 2
Picloram	.01	.01	.01	.01	.02
Silvex	<.01	<.01	<.01	<.01	<.01
Triazine herbicides					
Alachlor	< 1	< 1	< 1	< 1	< 1
Ametryn	<.1	<.1	<.1	<.1	<.1
Atraton	<.1	<.1	<.1	<.1	<.1
Atrazine	<.1	<.1	<.1	.1	.3
Cyanazine	<.1	<.1	<.1	<.1	<.1
Cyprazine	<.1	<.1	<.1	<.1	<.1
Drometon	<.1	<.1	<.1	<.1	<.1
Prometryn	<.1	<.1	<.1	<.1	<.1
Propazin	<.1	<.1	<.1	<.1	<.1
Simazine	<.1	<.1	<.1	<.1	<.1
Simeton	<.1	<.1	<.1	<.1	<.1
Simetryn	<.1	<.1	<.1	<.1	<.1
Trifluralin	<.1	<.1	<.1	<.1	<.1
Carbamate insecticides					
Barban (anilide)	<.2	<.2	<.2	<.2	<.2
Carbaryl	< 2	< 2	< 2	< 2	< 2
Eptan	<.6	<.6	<.6	<.6	<.6
Methomyl	< 2	< 2	< 2	< 2	< 2
Propham	< 2	< 2	< 2	< 2	< 2
Sutan	<.4	<.4	<.4	<.4	<.4
Organochlorine compounds/ organophosphorus insecticides					
Aldrin	<.01	<.01	<.01	<.01	<.01
Chlorodane	<.1	<.1	<.1	<.1	<.1
DDD	<.01	<.01	<.01	<.01	<.01
DDE	<.01	<.01	<.01	<.01	<.01
DDT	<.01	<.01	<.01	<.01	<.01

Table 13.--Summary of pesticide analyses of water samples from Sand and Mud Lakes (July 20 and 21, 1982)--Continued

Pesticide group/compound	Concentration (micrograms per liter)[1/]				
	Sand Lake cross sections			Mud Lake cross sections	
	1	2	3	1	2
Organochlorine compounds/ organophosphorus insecticides--Cont.					
DEF (herbicide)	0.09	0.08	0.09	0.10	0.08
Diazinon	<.01	<.01	<.01	<.01	<.01
Dieldrin	<.01	<.01	<.01	<.01	<.01
Endosulfan	<.01	<.01	<.01	<.01	<.01
Endrin	<.01	<.01	<.01	<.01	<.01
Ethion	<.01	<.01	<.01	<.01	<.01
Heptachlor	<.01	<.01	<.01	<.01	<.01
Heptachlor Epoxide	<.01	<.01	<.01	<.01	<.01
Lindane	<.01	<.01	<.01	<.01	<.01
Malathion	<.01	<.01	<.01	<.01	<.01
Methoxychlor	<.01	<.01	<.01	<.01	<.01
Methyl Parathion	<.01	<.01	<.01	<.01	<.01
Methyl Trithion	<.01	<.01	<.01	<.01	<.01
Mirex	<.01	<.01	<.01	<.01	<.01
Parathion	<.01	<.01	<.01	<.01	<.01
PCB	<.1	<.1	<.1	<.1	<.1
PCN	<.1	<.1	<.1	<.1	<.1
Perthane	<.1	<.1	<.1	<.1	<.1
Toxaphene	<1	<1	<1	<1	<1
Trithion	<.01	<.01	<.01	<.01	<.01

1/ Total recoverable. Note: Less than symbol (<) indicates that compound was not detected at the indicated concentration.

ADDITIONAL STUDIES

Although this was a very short-term investigation (only 6 months), it became apparent during the study that additional data would have permitted improvement and expansion of some of the analyses. Areas for additional study are discussed in the following sections.

Drainage-Area Data

The need for improved drainage-area data became apparent in several aspects of the study, including the Sand Lake National Wildlife Refuge mass-balance computations, the frequency analyses, and the gain-loss computations.

Improved drainage-area data for the reach of the James River between LaMoure, N. Dak., and Columbia, S. Dak., in conjunction with correlation techniques, would provide better quantification of inflows to the refuge. For instance, flows from the intervening drainage area between LaMoure and the State line could be developed through correlation with the runoff from a local stream such as the Maple River at the State line (06471200) and these correlated flows could be added to the historic flows at LaMoure, thereby representing inflows to the refuge. Then, monthly mass-balance computations could be made for water years 1969-81 to more accurately determine unaccounted-for losses. It was noted in the discussion on Sand Lake that a 10 percent decrease in the estimation of refuge inflows from water years 1969 through 1981 decreased the estimation of unaccounted-for losses to about 39 percent (from 1.95 to 0.74 acre-feet per acre per year). Beginning in water year 1982, inflow data for the refuge are being collected at the gaging stations at Hecla, at the State line, and at Dakota Lake.

Improved drainage-area data also would facilitate improved interpretation of the tributary frequency analyses. The tributary gaging stations are located as much as 40 miles upstream from the mouths (table 2). With drainage-area data for the tributaries at their confluence with the James River, the results of the frequency analyses could be extended to the mouths. This would permit analysis of the localized effects that tributary inflows have on the main-stem flow regime.

The gain-loss analysis also could be improved with additional drainage-area data. Not only could the gaged tributary flows be extended downstream to the mouths, but ungaged inflows could be estimated through statistical means and included in the analysis. As was indicated in the gain-loss discussion, consideration of ungaged tributary inflows and adjustment of gaged tributary inflows would tend to decrease the estimated net gains and increase the estimated net losses.

Effects of Regulation

Additional studies are needed to more accurately assess the effects of regulation on the main-stem flow regime in South Dakota. Concerns relating to regulation have been expressed on numerous occasions by local interests along the upper James River within South Dakota.

Jamestown Reservoir, completed by the Bureau of Reclamation in 1953, provides about 221,000 acre-feet of total storage, of which about 185,500 acre-feet is for flood control (U.S. Water and Power Resources Service, 1981). Pipestem Reservoir, completed by the U.S. Army Corps of Engineers in 1973, provides 136,000 acre-feet of exclusive flood control storage, 10,000 acre-feet of storage for fish and wildlife, and 37,000 acre-feet of surcharge storage (Missouri River Basin Commission, 1980b).

A possible approach would be to create a synthetic record by eliminating the effects of regulation from the historic record through the use of a flow-routing model, and then comparing frequency analyses conducted on the two concurrent records (historic and synthetic). Once the synthetic record is established, other analyses such as flow-duration studies could be accomplished on both records and comparisons could be made.

Ground Water-Surface Water Relationships

Continuous lake-level recorders and a new observation-well network could be installed to evaluate whether or not there is significant surface water-ground water interchange occurring between Sand and Mud Lakes and the sands which extend to the east of the lakes. The wells would be relatively shallow (15-25 feet).

Although the Fish and Wildlife Service has maintained records of average, minimum, and maximum lake levels from 1969 to 1981, and the Bureau of Reclamation and U.S. Geological Survey installed observation wells in the area during the 1950's, concurrent records of lake levels and observation-well water levels are not available. Furthermore, most of the observation wells have been destroyed or are no longer operable. Installation and monitoring of a properly located observation-well network, in conjunction with continuous lake-level monitoring, would permit an assessment of possible ground water-surface water interchange.

Sand and Mud Lakes

If additional studies on Sand and Mud Lakes are to be made, additional cross-section data need to be obtained to more accurately define the area-capacity curves for the lakes. The degree of detail required for additional area-capacity data will depend, to a large extent, on the degree of detail desired for future studies (water-loss computations, retention time, and so forth). The streamflow gages that have been installed on the James River at Hecla, S. Dak., at the North Dakota-South Dakota State line, and at Dakota Lake Dam near Ludden, N. Dak., will provide daily flow data representing inflows to the refuge. If continuous lake-level recorders were installed on both lakes to define daily changes in storage, daily operation studies could be conducted using the three upstream gages to represent inflows to the refuge and the Columbia gaging station to represent outflow from the refuge.

The Bureau of Reclamation also requested that an analysis of traveltime through the refuge be conducted. This cannot be done now because historic streamflow data immediately upstream from the refuge are not available. Traveltime through the refuge could possibly be analyzed by conducting a dye-tracing study although it may be impossible to successfully pass the dye through the refuge. A dye-tracing analysis was not conducted due to its questionable success, as well as time, funding, and personnel constraints. Flow data being collected at the gaging station at Hecla, in conjunction with data from the gaging station at Columbia, should permit a future evaluation of traveltime through the refuge, once flow conditions that will allow for this evaluation occur on the James River.

A series of aerial photographs at different times of the year, and at various lake levels, might assist in the determination of open-water surface area, as well as the estimation of water loss associated with plant growth in the lakes. Color-infrared photographs taken in September 1980 were provided by the Bureau of Reclamation, but were not specifically used for the current study.

Hydraulic-Flow Models

In this report, several items that indicate the complex nature of the flow-routing process on the James River in South Dakota have been discussed. These items include, but are not limited to, frequent flooding with substantial overbank storage, attenuation of flood peaks in certain reaches, major water loss in Sand Lake National Wildlife Refuge, and along the reach of the river within the Lake Dakota Plain, and reverse flows resulting from tributary inflows at certain locations on the river.

Model studies would be very useful to evaluate potential downstream impacts of proposed development plans such as the Garrison Extension. Several U.S. Geological Survey surface-water modeling programs have potential for application to such an evaluation, given adequate data.

SUMMARY

The James River within the Lake Dakota Plain has little slope and very restricted channel capacities at several locations. Between the gaging station at Columbia and the gaging station at Redfield, the average slope is only 0.30 foot per mile. Near Stratford, the slope is less than 0.10 foot per mile and channel capacities are as little as 200 cubic feet per second. Channel capacities slowly increase toward the southern end of the Lake Dakota Plain, and are 3,000 to 4,000 cubic feet per second near Redfield. The traveltime between Columbia and Redfield is estimated to be about 15 days for most flows. Downstream from Huron, the slope and channel capacities increase slightly. Although the average slope is still only 0.30 foot per mile, there are no areas with virtually no slope as in reaches of the James River within the Lake Plain. Channel capacities of the river south of the Lake Dakota Plain generally are greater than 2,000 cubic feet per second and the traveltime between Huron and Scotland is estimated to be about 10 days for most flows.

The recurrence interval for extended periods of overbank flooding on the James River in South Dakota is 10 years or less. In the vicinity of Stratford, the recurrence interval for flooding is less than 2 years. Conversely, there commonly is little or no flow from late summer until spring snowmelt. Additional detailed studies are needed to assess the effects of regulation by Jamestown and Pipestem Reservoirs on the flow regime (flood frequency, flow duration, and so forth) in South Dakota.

The analysis of stream gains and losses indicated that the James River within the Lake Dakota Plain tends to lose discharge with distance while the downstream reach generally gains discharge with distance. The trend of gradual loss on the James River within the Lake Dakota Plain probably is due to bank storage and evapotranspiration of water from the river. Major losses along the river within the Lake Dakota Plain are associated with the occurrance of flooding when water is trapped in the overbank area and evaporated or transpired before it can re-enter the river. The trend of gradual gains for the downstream reach probably is indicative of actual conditions although the lack of tributary records would result in an over-estimation of gains. The availability of improved drainage-area data would permit the extension of historic records for certain tributaries, as well as the estimation of flows for ungaged tributaries, and including these data in the gain-loss study.

Interaction between underlying aquifers and the river does not appear to be significant in the upstream reach of the James River. Some interaction, although not quantified, does occur in Hanson, Davison, and Yankton Counties.

Analysis of Fish and Wildlife Service operating records and computation of evaporation losses during 1969-81 indicated that Sand Lake National Wildlife Refuge (Sand and Mud Lakes) is a major source of water loss from the James River. Net evaporation losses (gross evaporation minus precipitation gains) are estimated to have been slightly more than 14,000 acre-feet per year during water years 1969-81. A mass-balance computation indicated that there may have been as much as 19,000 acre-feet per year of unaccounted-for losses occurring in the two lakes during the 13 years. Unaccounted-for losses include water use by lake vegetation, lake seepage losses, and so forth. However, inflows to the refuge were estimated by extending historic flows at LaMoure, N. Dak., downstream to the State line through a drainage-area ratio that may have introduced significant error into the mass-balance computation. Additional studies, including the determination of the drainage area between the gage at LaMoure and the State line and streamflow correlations with nearby streams, are needed to more accurately estimate inflows to the refuge for water years 1969-81. Additional studies also are needed to assess the traveltime of flows through the refuge. The traveltime analysis may be facilitated by the use of flow data being collected at gaging stations installed upstream from the refuge in 1981. Additional studies would be necessary to ascertain whether or not there is surface water - ground water interchange between Sand and Mud Lakes and the sands which extend to the east of the lakes.

Water-quality analyses of water samples collected in Sand and Mud Lakes indicated detectable, although not excessive, concentrations of certain pesticides (2,4-D; DEF; Atrazine; Dicamba; and Picloram). Dissolved-oxygen monitoring indicated probable photosynthetic activity in both lakes.

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SUPPLEMENTAL INFORMATION

Historic streamflow in the James River at eight sites

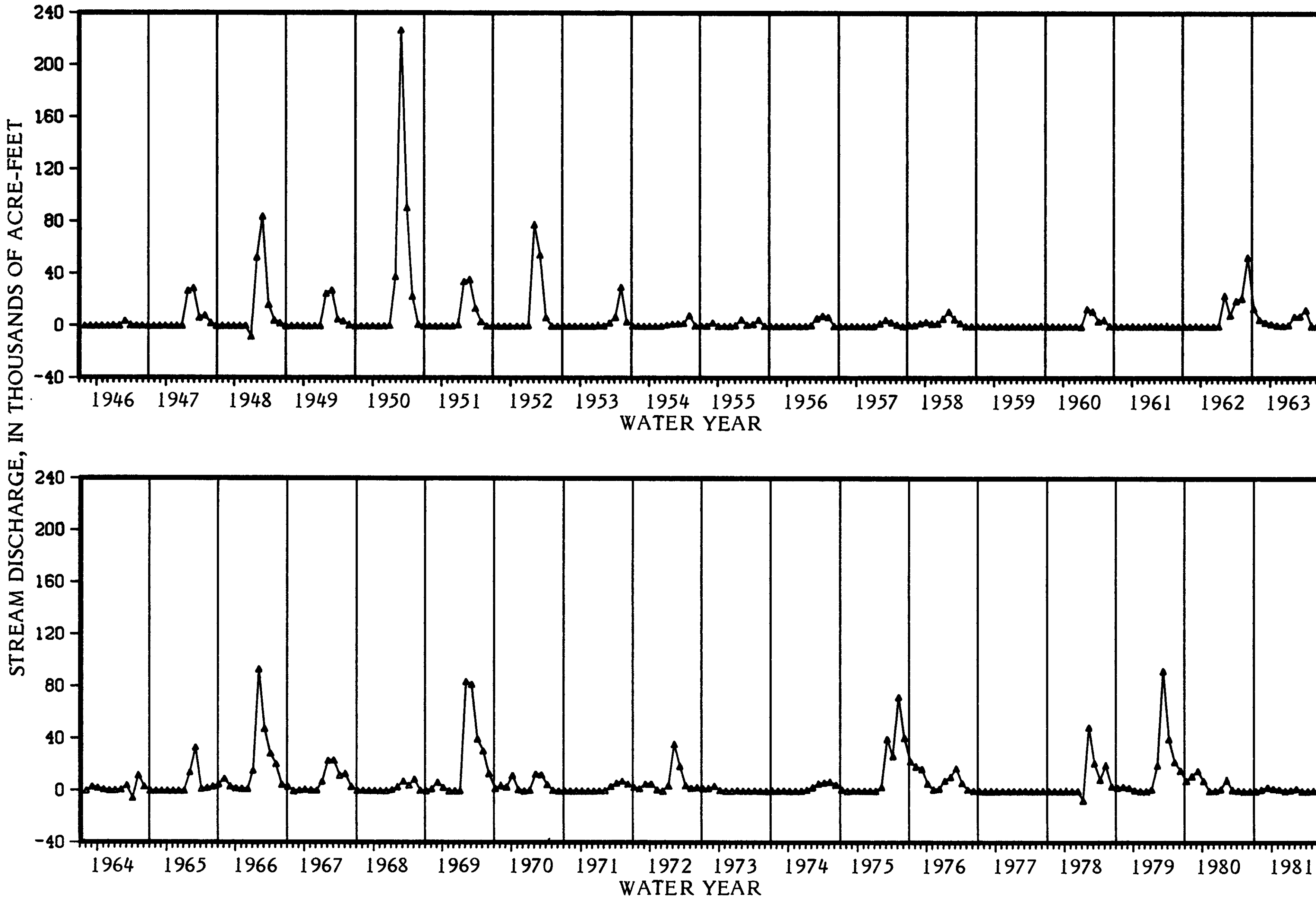

Figure 30.—Historic streamflow for James River at Columbia, S. Dak., water years 1946-81.

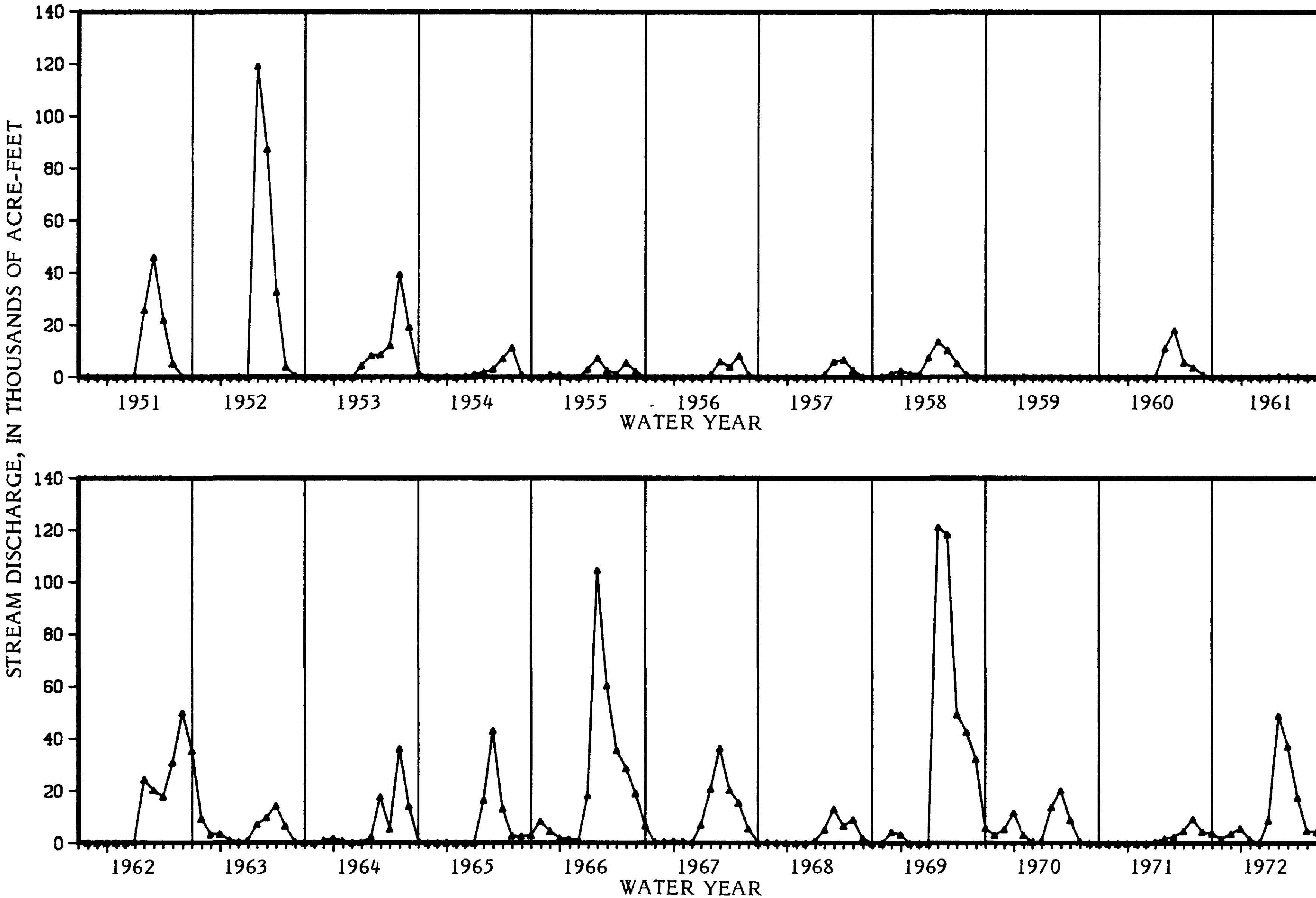

Figure 31.--Historic streamflow for James River near Stratford, S. Dak., water years 1951-72.

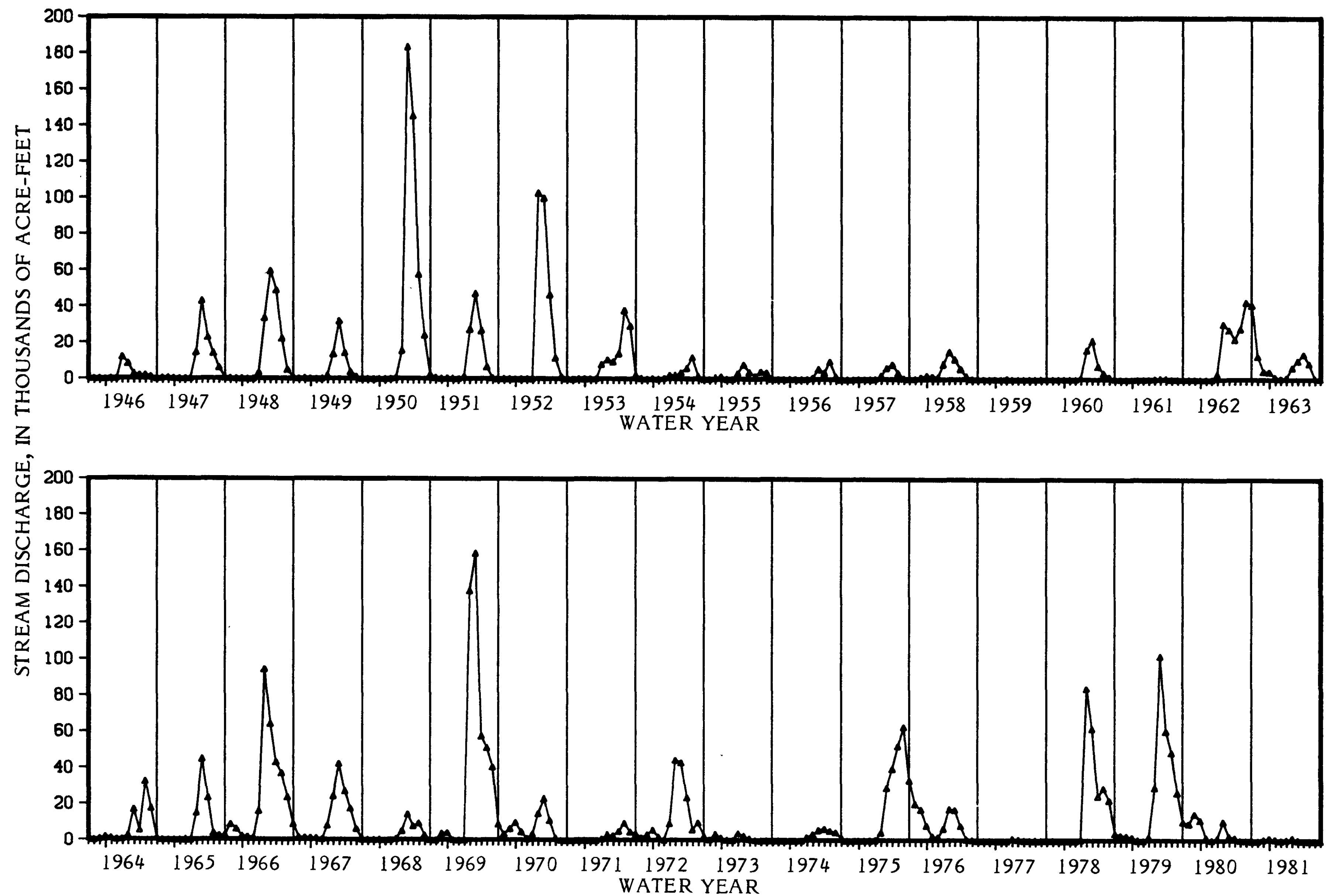

Figure 32.—Historic streamflow for James River at Ashton, S. Dak., water years 1946-81.

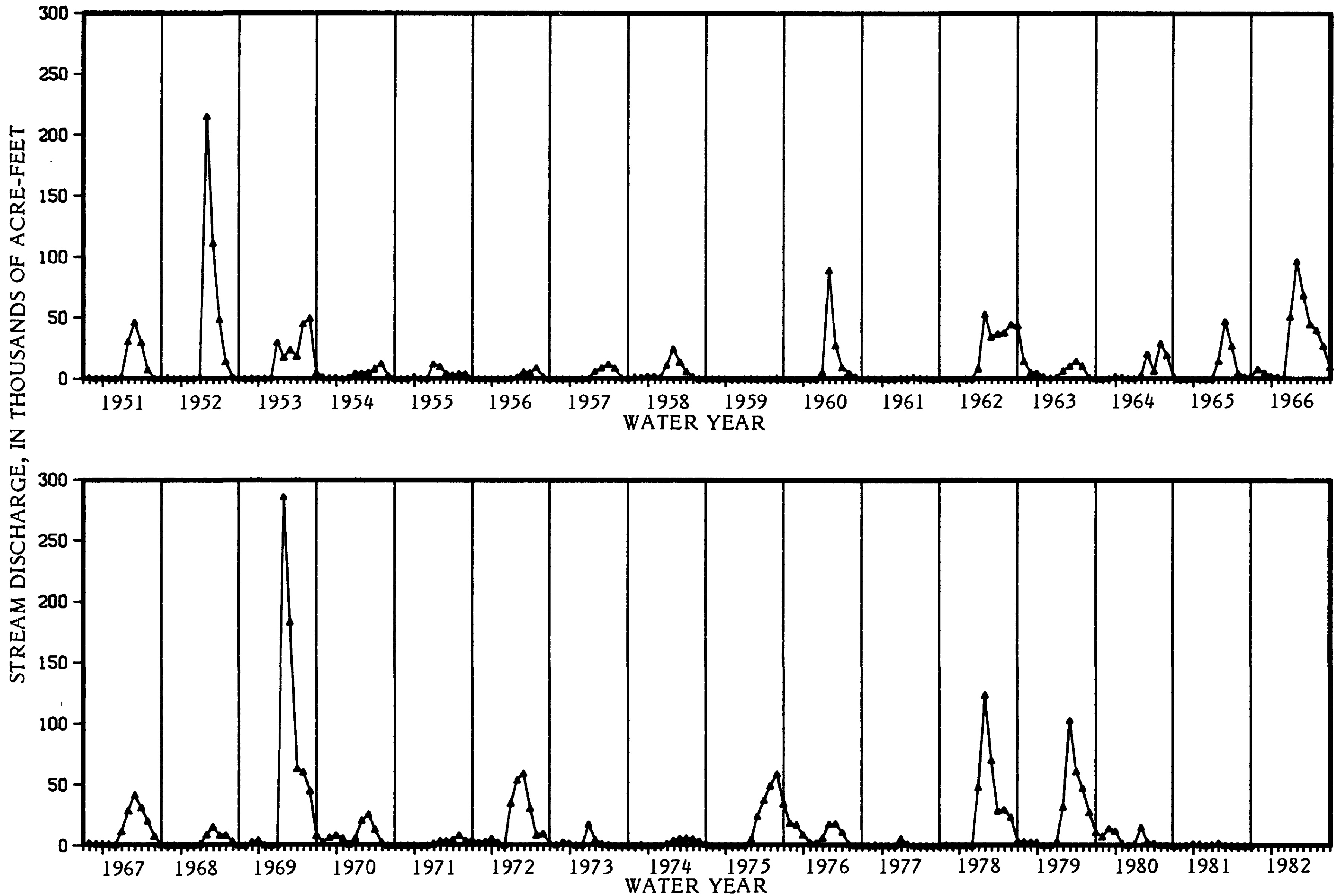

Figure 33.--Historic streamflow for James River near Redfield, S. Dak., water years 1951-81.

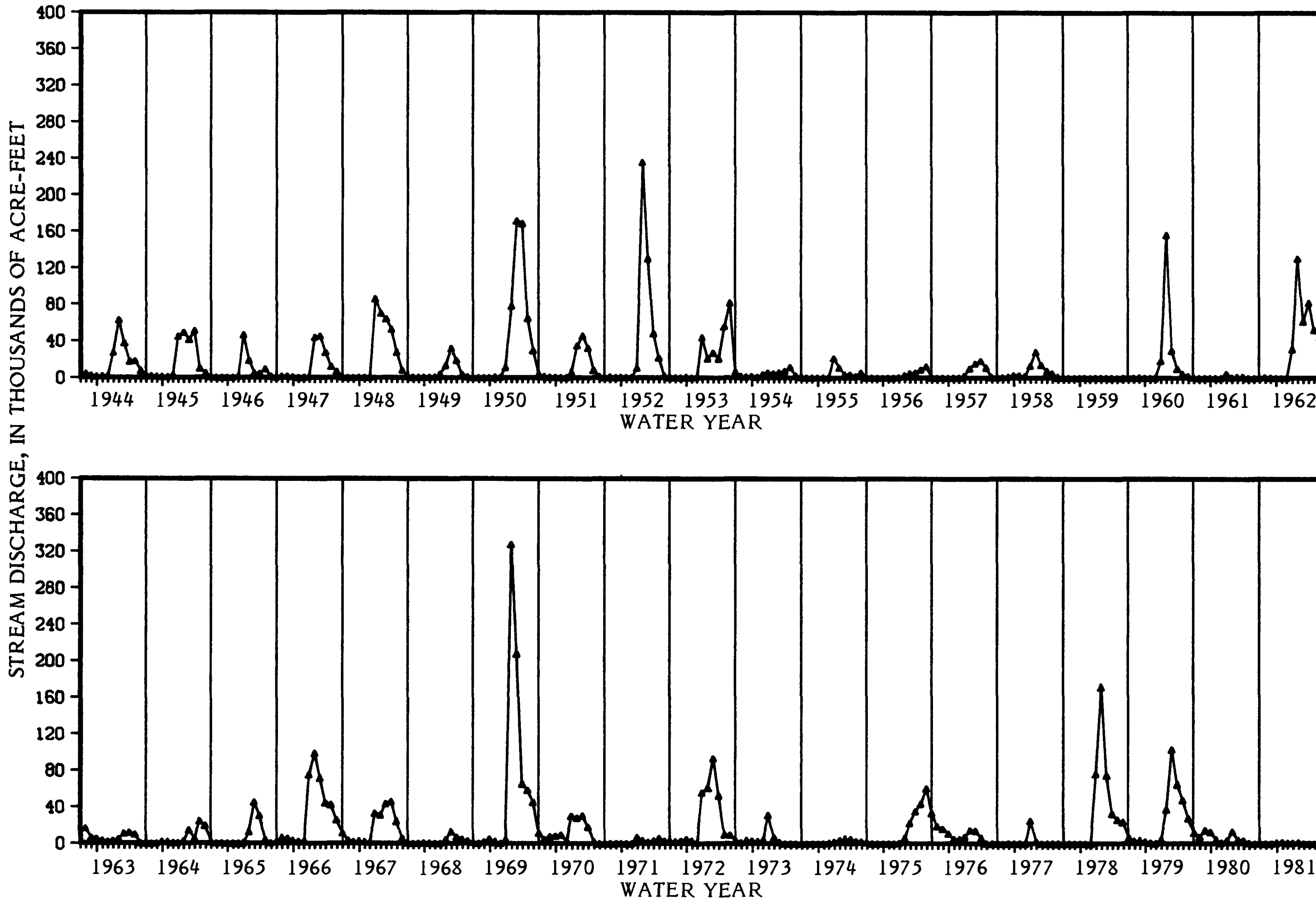

Figure 34.--Historic streamflow for James River at Huron, S. Dak., water years 1944-81.

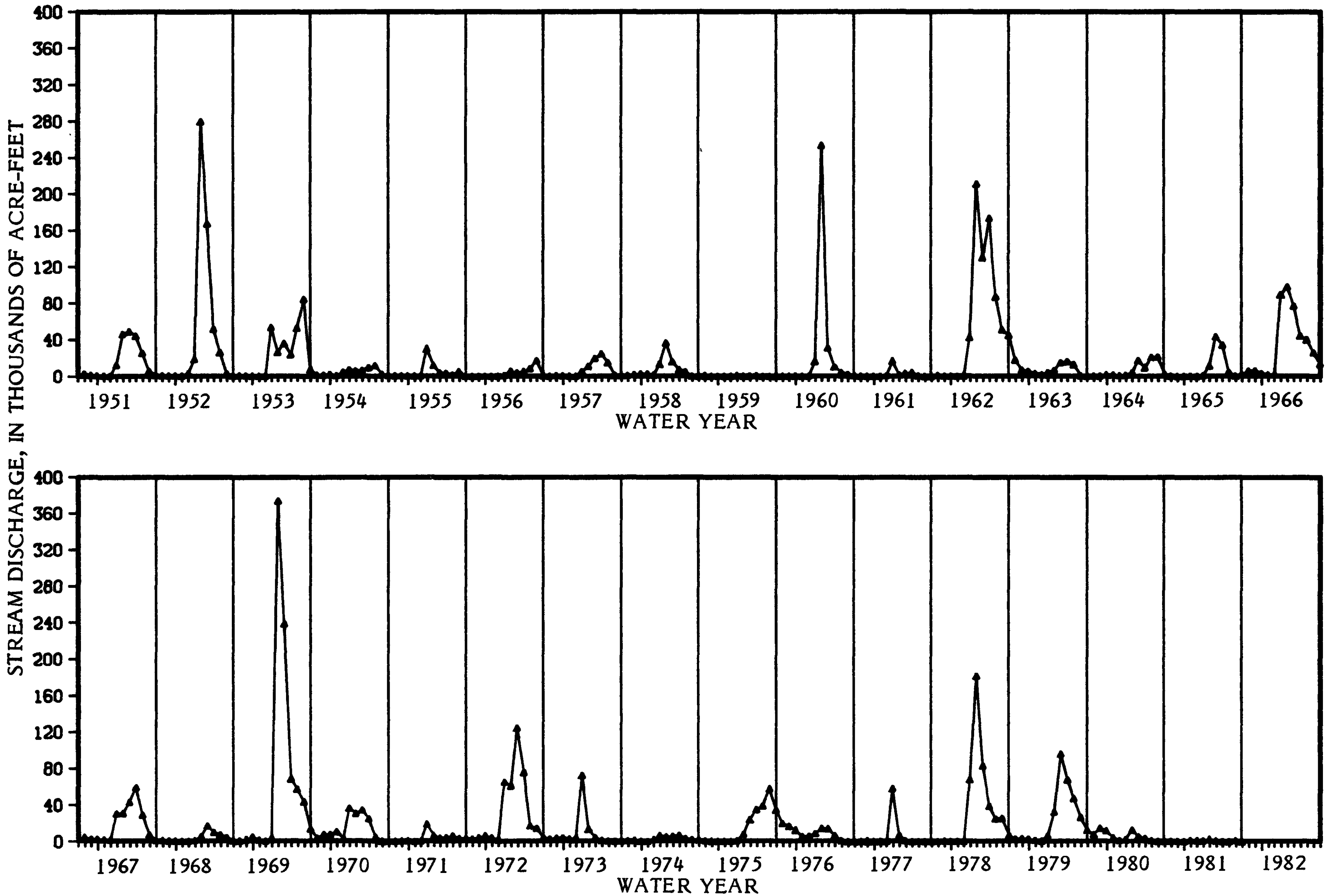

Figure 35.—Historic streamflow for James River near Forestburg, S. Dak., water years 1951-81.

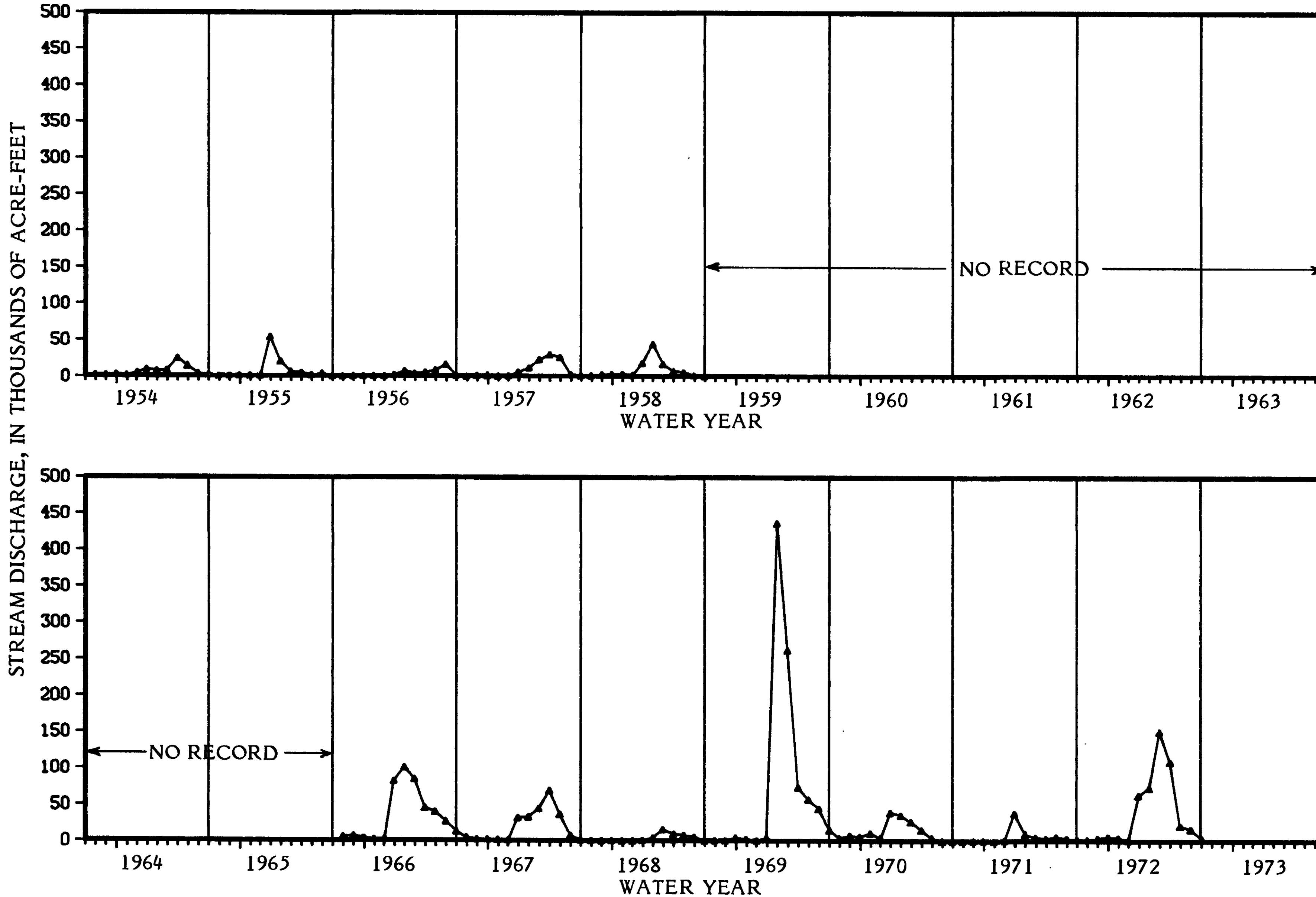

Figure 36.--Historic streamflow for James River near Mitchell, S. Dak., water years 1954-58, 1966-72.

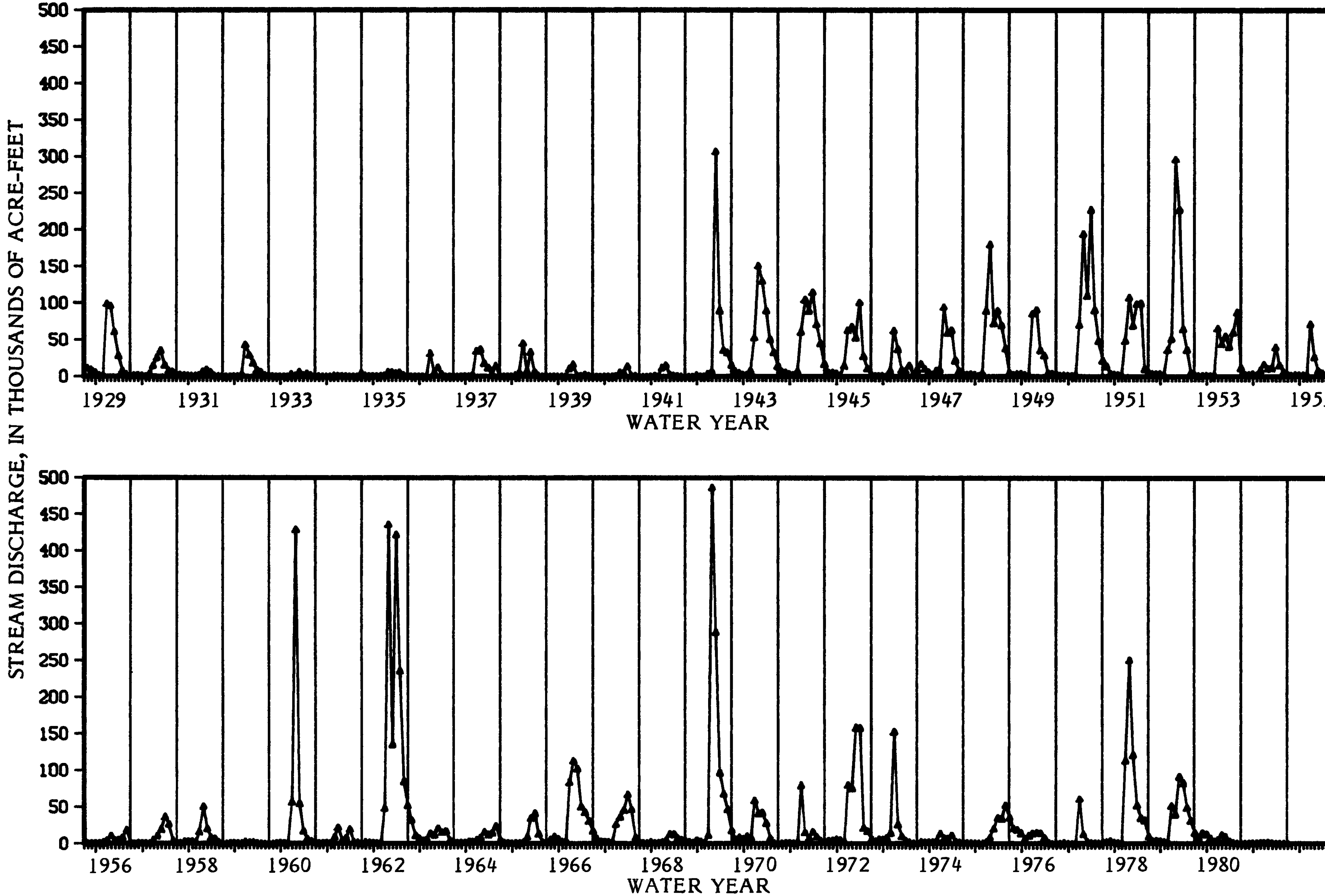

Figure 37.--Historic streamflow for James River near Scotland, S. Dak., water years 1928-81.

Gains and losses in seven reaches of the James River

Table 14.—Cumulative streamflow gains or losses in the James River between LaMoure, N. Dak., and Columbia, S. Dak., during water years 1951-81 (units in acre-feet)

WATER YEAR	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.
1951	-2220	-3910	-5180	-6510	-7605	-10132	-23642	-1502	6928	8168	7088	6068
1952	4926	3748	2780	2187	1594	713	-11797	34203	38583	35562	34606	33506
1953	32663	31633	30926	30176	29268	24357	22077	20547	2507	24287	25667	24980
1954	24099	23161	22383	21699	19328	18453	18203	18683	4133	3573	2649	1841
1955	1199	3083	2429	1697	1506	-443	-4063	-4604	-7734	-8114	-9533	-10150
1956	-10930	-11640	-12136	-12523	-12900	-15404	-20676	-18016	-26746	-22386	-23420	-24255
1957	-25239	-27329	-28499	-28961	-29227	-30526	-31386	-28666	-27136	-26951	-27672	-28139
1958	-29713	-29513	-27783	-26661	-25651	-33781	-30861	-28351	-28901	-30669	-31311	-31959
1959	-32555	-33460	-33936	-34163	-34269	-35349	-36789	-37999	-39569	-41219	-41590	-41911
1960	-42625	-43289	-43935	-44432	-44798	-51155	-65305	-56615	-54935	-51086	-51470	-51709
1961	-52080	-52545	-52960	-53417	-53756	-56186	-57795	-58957	-59428	-59729	-59926	-60536
1962	-61000	-61585	-61914	-62373	-62671	-70242	-56132	-51312	-56912	-66532	-24462	-15512
1963	-12662	-11942	-11612	-11581	-11669	-12755	-9215	-4675	5775	4782	3632	3059
1964	2521	4836	6473	7016	6775	6455	3109	4659	-12011	-4421	-2461	-3237
1965	-4072	-4089	-5276	-5791	-6211	-6819	-26279	-4009	-6499	-9689	-16059	-21159
1966	-21649	-20659	-22139	-22439	-23069	-62369	-28529	-13099	-8629	-1519	-649	-2749
1967	-7261	-8084	-7983	-8103	-8361	-15141	-8671	-441	-4591	-671	379	-336
1968	-629	-1484	-1967	-2516	-3119	-5586	-5656	-1618	-7408	-506	-906	-1740
1969	-1003	4681	6661	6417	6280	5999	-11241	41689	54399	59979	55229	51479
1970	49969	51499	61869	61739	60773	59036	65576	71096	73326	72677	72563	72309
1971	71696	71197	70653	70196	69703	64534	54600	48160	43570	46940	51571	53291
1972	49371	50961	54961	55015	54311	54151	58321	70911	70141	70231	69941	69071
1973	68461	71392	71069	70237	69497	64157	62427	61613	61386	61354	60797	59637
1974	58199	57914	57416	56971	56482	50376	45366	42656	25776	27396	30136	29642
1975	27286	26646	26306	26058	25756	24552	-9136	-6658	-13018	35302	58102	63522
1976	60652	67942	71432	71152	70542	68052	60192	68432	72232	71782	71055	70294
1977	69349	68618	67975	67477	66857	64941	63602	62840	61450	59300	58661	57700
1978	56010	55414	54896	54565	54273	20623	54903	63153	58463	69213	68613	67293
1979	69736	71600	71737	71220	70620	68290	18610	74520	85100	68410	68360	60240
1980	76700	60830	85740	64522	63659	78299	61689	61212	79721	78711	77732	73132
1981	70762	69912	69462	70392	69590	66236	65056	63536	62174	60960	60440	58144

Table 15.--Cumulative streamflow gains or losses in the James River between Columbia and Stratford during water years 1951-72 (units in acre-feet)

WATER YEAR	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.
1951	-81	-285	-410	-425	-520	-2946	-20661	-11128	-2957	-1296	-1318	-1480
1952	-1558	-1773	-1852	-1947	-2036	-2220	-68866	-38042	-12148	-8394	-8027	-8511
1953	-8467	-8880	-9091	-9219	-9280	-14621	-6061	-4653	-20221	-12890	2700	3852
1954	3717	3674	3815	3794	3300	3336	3419	4657	-3037	-982	-551	-602
1955	-1084	-2856	-2029	-2255	-2304	-3481	-3478	-2053	-2388	-7692	-6555	-6363
1956	-6695	-6988	-7143	-7224	-7414	-7834	-9639	-10234	-14214	-13206	-12605	-12978
1957	-13405	-13581	-13714	-13839	-13924	-14004	-15199	-14482	-10939	-9627	-10667	-10948
1958	-11508	-12526	-13248	-14019	-15793	-25106	-25070	-22519	-21236	-20614	-20968	-21342
1959	-21722	-21880	-22140	-22430	-22520	-22734	-22843	-22881	-22926	-23788	-24063	-24384
1960	-24914	-25153	-25370	-25500	-25693	-32661	-49970	-46265	-47181	-48540	-48095	-48564
1961	-48769	-49335	-49573	-49736	-49968	-50811	-50564	-50552	-50428	-50729	-51197	-51710
1962	-51848	-52320	-52502	-52724	-52769	-59872	-73450	-62806	-73422	-100451	-106199	-85096
1963	-81136	-80724	-79181	-78816	-78909	-79352	-60782	-79987	-83297	-77528	-77393	-77702
1964	-77910	-80038	-80474	-80075	-80925	-81214	-81738	-85645	-109373	-107914	-97708	-97448
1965	-97647	-98124	-96250	-98420	-98563	-98791	-113835	-106681	-96859	-96869	-97835	-100144
1966	-101030	-99993	-100136	-100385	-100868	-153551	-150288	-139355	-132991	-125249	-120173	-117192
1967	-117047	-116985	-117343	-117528	-117489	-119386	-128326	-124831	-117474	-115664	-113876	-114177
1968	-114394	-114640	-114801	-114913	-115114	-115622	-114459	-111343	-110427	-111363	-110069	-110349
1969	-112277	-114837	-114055	-114162	-114306	-114743	-220093	-189001	-182402	-175662	-158395	-154847
1970	-155802	-153641	-153859	-151934	-151638	-151152	-152498	-146367	-142883	-142962	-143552	-143935
1971	-144210	-144391	-144574	-144865	-145069	-147943	-147085	-148260	-150421	-152137	-153527	-152612
1972	-152960	-154943	-154936	-154601	-154833	-179397	-171072	-159734	-147924	-145727	-144281	-144563

Table 16.—Cumulative streamflow gains or losses in the James River between Stratford and Ashton during water years 1956-69 (units in acre-feet)

WATER YEAR	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.
1956	0	0	0	0	0	-12	-749	-1244	-1562	-31	487	522
1957	522	522	522	522	522	-344	-779	-1259	-1223	-546	-396	-547
1958	-589	-899	-1607	-1339	-1589	-971	501	1279	1835	2525	2559	2559
1959	2559	2559	2559	2559	2559	2559	2527	2521	2506	2506	2506	2506
1960	2506	2506	2506	2506	2506	2367	1937	4950	6472	6188	6451	6463
1961	6464	6464	6464	6464	6464	6408	6127	5979	5962	5937	5937	5937
1962	5907	5907	5907	5907	5907	4387	3312	8230	6979	2540	-5522	16
1963	3349	4395	5041	5178	5269	5225	4405	4865	4272	6453	6680	6661
1964	6661	6177	6042	6089	6069	6087	6097	4703	4520	646	4016	4378
1965	4411	4425	4427	4427	4427	4427	598	-439	6802	7253	6972	6480
1966	6769	8191	8502	8352	8577	-2925	-14580	-11506	-4514	-1428	2087	3782
1967	4325	4704	4864	5038	5062	2339	1324	3723	9270	10948	11538	11580
1968	11390	11429	11536	11562	11618	11424	10444	11063	12025	12226	13073	13116
1969	13116	12495	13098	13299	13302	13340	7979	46979	54964	61611	69421	72459

Table 17.--Cumulative streamflow gains or losses in the James River between Ashton and Redfield during water years 1956-69 (units in acre-feet)

WATER YEAR	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.
1956	-12	-22	-30	-46	-63	-24	125	-22	382	-583	-589	-643
1957	-788	-806	-818	-835	-850	-742	-1169	-1283	-1414	-1271	-1250	-1363
1958	-932	-983	-985	-880	-884	-594	-1397	60	-27	95	143	76
1959	75	66	51	36	19	215	282	301	297	257	251	244
1960	234	226	214	201	187	-2432	-3759	-1529	-31	961	1050	1021
1961	1115	1242	1277	1280	1279	1355	1238	1191	1183	1333	1357	1357
1962	1357	1357	1346	1340	1329	401	6177	8100	8462	10771	12093	14477
1963	15904	16460	16718	16991	17076	17179	16842	16629	16886	17892	17920	18095
1964	18090	17679	18148	18352	18518	18584	16935	16586	19129	15599	16516	16941
1965	16979	16981	16981	16981	16981	17046	15578	15400	17797	18099	17341	16879
1966	15727	14510	14549	14604	14654	9064	5000	8094	8895	8562	11278	11327
1967	11791	11922	11970	11961	12025	1563	1799	-522	-1773	-2402	-1021	-524
1968	-514	-510	-622	-673	-681	-897	915	309	661	-544	-98	104
1969	109	-798	-561	-345	-223	-431	-6397	3269	5609	5642	7051	5571

Table 18.--Cumulative streamflow gains or losses in the James River between Redfield and Huron during water years 1951-81 (units in acre-feet)

WATER YEAR	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.
1951	490	694	867	986	1030	4747	9065	8337	11102	12102	13514	13257
1952	13053	13065	13241	13288	13061	22664	42995	62167	61843	69825	70602	70583
1953	70750	70677	70620	70560	70910	85058	88634	92476	94732	105901	138429	140240
1954	140640	141154	141926	142504	145298	146532	146742	147369	146759	146111	145644	146479
1955	146553	146563	145211	145478	145553	155057	156301	155944	156850	154598	156018	155920
1956	155920	155920	155920	155920	155920	156177	157830	157094	157733	157767	168642	168977
1957	169005	169333	169393	169510	169831	171880	175966	182924	189864	192581	192675	192875
1958	192535	192429	193236	194101	194829	196741	200815	201107	202646	205810	205782	205782
1959	205782	205782	205782	205782	205782	205857	205858	205829	205820	205820	205820	205820
1960	205820	205820	205820	205820	205820	219342	280965	289556	290336	290179	290778	291118
1961	291006	290868	290829	290823	290822	295101	295385	295736	296356	296181	296109	296109
1962	296909	296973	296973	296973	297181	320515	396324	425388	470787	465863	466026	486967
1963	489371	490827	491493	492696	494086	495986	494348	495330	492902	492893	492411	492156
1964	492158	492094	492292	492642	493340	493661	493330	487797	487142	482758	483012	482887
1965	482821	483165	483161	483161	483159	483290	481689	479712	483435	483215	482286	482151
1966	480239	480993	482183	482077	483790	508212	510433	513474	513500	516166	515457	517767
1967	519243	519797	520840	521939	523032	545011	547526	550004	565023	569345	567613	567621
1968	567623	567812	568482	569218	569639	569519	565149	563094	561795	558177	558023	559045
1969	559345	558631	559363	560381	560717	564347	605659	630554	633660	632416	633495	637565
1970	639243	640746	641228	645017	646659	671183	678958	684111	689374	689024	688928	688928
1971	688912	688969	689076	689074	689265	694982	694413	692640	691089	688344	687299	685867
1972	685678	685582	684636	685437	686250	707304	714712	748874	771141	772734	772682	774128
1973	774784	775121	776352	778244	781313	795150	797255	797685	797319	797313	797313	797313
1974	797313	797352	797354	797354	798103	798358	797961	796738	795510	793073	791768	792085
1975	792098	792208	792209	792209	792209	792930	793766	792253	790432	785076	786802	786143
1976	786925	786166	786457	790724	793348	794689	791771	788092	782909	782228	782228	782228
1977	782228	782228	782243	782243	782243	801562	802604	802514	802509	802509	802509	802509
1978	802509	802509	802609	802681	802681	831263	878847	863431	887882	884934	865537	888567
1979	888750	888889	889111	889893	890311	892054	897773	898150	901958	902483	903108	904564
1980	904768	905474	906343	908650	909380	911456	909550	910726	912591	913144	912938	912930
1981	912910	912659	911442	911682	912080	911920	911229	911136	911117	911116	911809	911809

Table 19.—Cumulative streamflow gains or losses in the James River between Huron and Forestburg during water years 1951-81 (units in acre-feet)

WATER YEAR	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.
1951	1476	2248	2476	2922	3316	5165	14511	15479	25204	39320	42750	43909
1952	44676	45624	46203	46687	49634	56612	79968	116581	119725	123937	124484	124833
1953	125463	126225	126697	127100	126776	134309	139206	145977	147086	142553	145059	146015
1954	146117	146469	147025	147136	147582	148714	149718	150262	151346	151613	151803	152193
1955	152750	153574	153904	154209	154547	157558	158540	158915	158674	158562	158320	158491
1956	158667	158726	158868	159040	159205	159997	162552	161547	161444	160987	165298	165630
1957	165854	166359	166739	166975	166995	169678	169346	172096	177765	179844	180250	180599
1958	180761	181378	181342	181406	181290	179239	185390	187359	187130	187016	187203	187276
1959	187403	187812	188113	188229	188283	188986	189176	189511	190237	190253	190262	190319
1960	190526	190821	191245	191481	191784	178019	266650	267688	268013	267879	268103	268594
1961	268877	269084	269350	269521	270387	281516	282616	284128	285583	286219	286296	286331
1962	286726	287180	287545	287692	287827	297127	368251	431345	515584	545141	551182	551179
1963	552322	552278	552332	552319	552322	553357	555020	558465	562655	565586	566121	566400
1964	566895	567039	566693	566963	567249	567817	568956	570827	574543	570648	572252	573028
1965	573219	573209	573609	574122	574522	575087	573426	571131	574638	574925	574697	574923
1966	575169	575871	575992	575790	575770	583579	582662	588121	567826	585321	585298	586980
1967	587765	587892	587946	587667	587774	583685	583167	582469	588417	592161	593156	593302
1968	594050	594231	594066	593708	593711	594271	594804	598665	601310	603591	604666	603952
1969	604176	603623	603526	603695	603701	603439	637714	668264	671110	669795	667675	669971
1970	669269	668668	667333	668200	668589	673295	673102	676490	682675	685065	685343	685363
1971	685598	686040	686520	686652	686780	695944	698564	700022	700747	701108	700951	700966
1972	701159	702076	703307	703781	703771	707771	707010	731651	754171	760967	765587	766248
1973	767463	767712	768172'	767581	765610	801751	807974	810345	811059	811516	811736	811686
1974	812565	813413	813839	813772	814509	818766	819812	820409	822032	822273	821999	822110
1975	822783	822944	823130	823276	823484	823478	824980	825997	825224	820201	817301	818144
1976	818056	819272	820121	820528	821333	822527	821985	821719	822407	822839	822839	822839
1977	822839	822839	822824	822824	822824	854709	858732	859409	859594	859652	859656	859667
1978	859773	860310	860361	860325	860355	843622	853192	861211	867061	865375	866607	866956
1979	866476	866484	866445	866270	866315	868089	862908	855658	858820	858400	857026	857141
1980	857452	857292	856201	856399	856647	855149	854651	855911	855649	855608	855680	855717
1981	855857	856222	855887	855663	855768	855744	856189	856590	856613	856615	856868	856870

Table 20.—Cumulative streamflow gains or losses in the James River between Forestburg and Scotland during water years 1951-81 (units in acre-feet)

WATER YEAR	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.
1951	11544	14501	15711	17377	18849	55867	117709	138360	195729	268817	273936	278165
1952	281279	284066	286972	289033	322362	355495	372612	433010	446387	457017	459564	461635
1953	461989	463020	464343	465636	467586	480390	498759	518078	535211	543284	547025	551876
1954	553179	554494	556251	557660	562101	571844	577237	582641	613563	617772	621680	624041
1955	625452	627372	629111	630716	632940	675545	690100	694309	696134	696914	695639	696258
1956	696645	697256	698096	698942	699872	703367	708597	709670	710086	710120	712345	713099
1957	713131	713780	714659	715587	716082	716324	716314	716679	729251	741519	744307	745368
1958	745678	746880	747394	748116	748663	751849	766436	770976	772271	774591	776148	776392
1959	776424	777610	778451	779198	779892	781979	783671	785300	785548	785868	785880	786078
1960	786139	786852	787935	788919	789638	830596	1006414	1030819	1038299	1040681	1041967	1043072
1961	1043805	1044735	1046018	1047101	1055546	1061808	1064068	1068918	1084516	1086606	1088001	1088430
1962	1088614	1090044	1090956	1091646	1093233	1099418	1324574	1329554	1578384	1727845	1762131	1770446
1963	1785104	1790160	1792100	1793345	1797376	1807593	1813143	1819722	1819728	1824299	1828348	1829838
1964	1830981	1832286	1832312	1833551	1835564	1840032	1844503	1843432	1846702	1840949	1844234	1847148
1965	1848303	1849257	1849807	1850375	1851292	1852384	1850367	1842408	1850052	1859283	1860734	1860422
1966	1860380	1863897	1867101	1868259	1869625	1864095	1879428	1904876	1911199	1914270	1919554	1924077
1967	1926162	1927594	1928413	1929236	1930289	1926713	1932713	1935768	1944368	1962156	1963622	1964721
1968	1965221	1965851	1966775	1967612	1968618	1970084	1969687	1965894	1968971	1969607	1970985	1975046
1969	1977207	1977534	1977516	1979309	1980549	1988402	2101739	2152398	2181510	2192853	2196868	2201474
1970	2203577	2205059	2204653	2204567	2210162	2232986	2244062	2252718	2256203	2259158	2259874	2260350
1971	2260085	2261984	2263017	2263788	2265792	2326295	2335375	2339293	2351591	2355030	2356347	2355677
1972	2356357	2357247	2357325	2358763	2360292	2375646	2390594	2424194	2506672	2511466	2514479	2516589
1973	2517995	2520795	2522132	2527438	2538599	2618990	2632519	2636829	2641868	2642561	2642892	2643678
1974	2645554	2646966	2648741	2651012	2652681	2660183	2662692	2664513	2669454	2669428	2669281	2669011
1975	2669614	2670589	2671368	2672196	2672873	2674681	2675064	2671900	2672613	2668317	2663904	2665866
1976	2667054	2669522	2671523	2672731	2678471	2684259	2685033	2685735	2687350	2687677	2688127	2688328
1977	2688634	2688967	2689395	2689627	2690281	2693809	2700268	2702078	2703119	2703773	2704117	2706445
1978	2708840	2712514	2714406	2715451	2716464	2762232	2851654	2870054	2883792	2894340	2901292	2904379
1979	2905702	2906638	2908046	2909443	2910690	2956750	2964171	2960129	2975255	2977175	2982411	2985204
1980	2985311	2985452	2986541	2989657	2991301	2994300	2995310	2996131	2995952	2996281	2996754	2997094
1981	2997276	2997316	2997961	2997711	2998356	2999113	2998401	2998916	2999199	2999644	2999563	3000156

Annual operating records of U.S. Fish and Wildlife Service
for Sand and Mud Lakes, 1969-81

Table 21.--Annual operating records of U.S. Fish and Wildlife Service for Sand and Mud Lakes, 1969-81

Month	Maximum elevation (feet above sea level)	Average elevation (feet above sea level)	Area (acres)	Capacity (acre-feet)
Calendar year 1969				
Sand Lake[1/]				
January	1,284.54	1,284.54	3,500	6,000
February	1,284.54	1,284.54	3,500	6,000
March	1,284.54	1,284.54	3,500	6,000
April	1,292.35	1,288.45	6,700	25,800
May	1,291.20	1,290.35	7,200	43,000
June	1,288.70	1,288.35	6,675	25,700
July	1,288.00	1,287.80	6,300	21,500
August	1,287.60	1,287.50	6,120	19,000
September	1,288.20	1,287.85	6,400	22,000
October	1,288.20	1,288.15	6,640	25,500
November	1,288.10	1,287.75	6,200	21,000
December	1,287.60	1,286.20	5,930	12,100
Mud Lake[2/]				
January	1,286.00	1,286.00	1,000	1,500
February	1,286.00	1,286.00	1,000	1,500
March	1,286.00	1,286.00	1,000	1,500
April	1,293.05	1,290.50	8,300	25,000
May	1,291.20	1,291.10	8,700	29,000
June	1,288.90	1,288.50	6,240	11,200
July	1,288.10	1,287.95	5,510	8,601
August	1,287.80	1,287.80	5,350	7,840
September	1,287.80	1,287.80	5,350	7,840
October	1,287.80	1,287.75	5,300	7,500
November	1,287.70	1,287.70	5,230	7,250
December	1,287.70	1,286.35	1,900	2,000

Table 21.—Annual operating records of U.S. Fish and Wildlife Service for Sand and Mud Lakes, 1969-81—Continued

Calendar year 1970

Month	Maximum elevation (feet above sea level)	Average elevation (feet above sea level)	Area (acres)	Capacity (acre-feet)
Sand Lake[1/]				
January	1,284.80	1,284.25	3,150	5,200
February	1,283.70	1,283.70	2,000	3,100
March	1,283.70	1,283.70	2,000	3,100
April	1,286.00	1,285.90	5,100	11,250
May	1,286.00	1,285.90	5,100	11,250
June	1,284.70	1,283.80	2,200	3,800
July	1,283.48	1,283.20	1,700	2,500
August	1,282.60	1,282.30	1,500	1,550
September	1,282.00	1,282.00	1,000	650
October	1,282.00	1,282.00	1,000	650
November	1,282.00	1,282.00	1,000	650
December	1,282.00	1,282.00	1,000	650
Mud Lake[2/]				
January	1,286.30	1,286.30	1,800	1,920
February	1,286.30	1,286.30	1,800	1,920
March	1,286.30	1,286.30	1,800	1,920
April	1,288.96	1,288.86	6,868	14,100
May	1,287.86	1,287.83	5,400	8,200
June	1,288.08	1,287.53	4,966	6,400
July	1,288.08	1,287.80	5,390	8,170
August	1,287.60	1,287.30	4,762	5,123
September	1,287.00	1,286.70	3,150	4,000
October	1,286.40	1,286.40	2,500	2,800
November	1,286.70	1,286.50	2,850	3,300
December	1,286.60	1,286.40	2,500	2,800

Table 21.—Annual operating records of U.S. Fish and Wildlife Service for Sand and Mud Lakes, 1969-81—Continued

Calendar year 1971				
Month	Maximum elevation (feet above sea level)	Average elevation (feet above sea level)	Area (acres)	Capacity (acre-feet)
		Sand Lake[1/]		
January	1,282.00	1,282.00	650	400
February	1,282.00	1,282.00	650	400
March	1,282.00	1,282.00	650	400
April	1,287.10	1,286.02	5,750	11,000
May	1,287.58	1,287.40	6,350	19,800
June	1,288.20	1,288.16	6,550	23,300
July	1,288.25	1,287.94	6,500	22,800
August	1,285.22	1,286.86	6,150	16,200
September	1,284.10	1,285.88	5,730	10,200
October	1,286.80	1,286.20	5,770	12,100
November	1,285.40	1,285.20	4,050	7,100
December	1,285.15	1,285.15	4,025	7,000
		Mud Lake[2/]		
January	1,286.10	1,286.10	1,800	1,300
February	1,286.10	1,286.10	1,800	1,300
March	1,288.20	1,287.15	4,750	4,900
April	1,289.10	1,288.70	6,800	14,700
May	1,288.60	1,288.40	6,300	12,900
June	1,288.42	1,288.40	6,300	12,900
July	1,288.44	1,287.78	5,700	7,900
August	1,287.10	1,286.68	3,750	3,200
September	1,286.57	1,286.40	3,400	2,600
October	1,288.20	1,287.30	4,950	5,900
November	1,288.45	1,287.85	5,800	8,700
December	1,286.30	1,286.15	1,900	1,400

Table 21.—Annual operating records of U.S. Fish and Wildlife Service for Sand and Mud Lakes, 1969-81--Continued

Calendar year 1972

Month	Maximum elevation (feet above sea level)	Average elevation (feet above sea level)	Area (acres)	Capacity (acre-feet)
		Sand Lake[1/]		
January	1,285.15	1,285.15	3,750	5,900
February	1,285.15	1,285.15	3,750	5,900
March	1,288.00	1,287.90	6,500	22,600
April	1,287.70	1,287.00	6,200	16,000
May	1,286.50	1,286.30	5,900	12,600
June	1,287.20	1,287.20	6,300	18,200
July	1,287.10	1,287.20	6,300	18,200
August	1,287.30	1,286.80	6,200	15,000
September	1,286.00	1,286.00	5,800	11,200
October	1,286.20	1,286.10	5,800	11,200
November	1,286.00	1,285.50	5,150	8,250
December	1,284.80	1,284.80	2,900	5,800
		Mud Lake[2/]		
January	1,286.00	1,286.00	1,500	1,800
February	1,286.00	1,286.00	1,500	1,800
March	1,289.45	1,289.30	7,750	17,500
April	1,289.10	1,288.50	6,500	13,500
May	1,287.90	1,287.70	5,500	7,900
June	1,287.50	1,287.40	5,200	6,400
July	1,287.30	1,287.20	4,850	5,200
August	1,288.30	1,288.15	5,900	9,300
September	1,288.00	1,287.60	5,500	7,900
October	1,286.00	1,285.80	1,250	1,400
November	1,285.60	1,285.60	900	1,150
December	1,285.40	1,285.40	700	1,000

Table 21.—Annual operating records of U.S. Fish and Wildlife Service for Sand and Mud Lakes, 1969-81

Calendar year 1973

Month	Maximum elevation (feet above sea level)	Average elevation (feet above sea level)	Area (acres)	Capacity (acre-feet)
		Sand Lake[1/]		
January	1,285.00	1,285.00	3,325	6,400
February	1,285.00	1,285.00	3,325	6,400
March	1,286.10	1,285.60	5,500	9,000
April	1,287.50	1,287.30	6,300	19,000
May	1,287.60	1,287.40	6,350	19,600
June	1,287.30	1,287.10	6,250	18,000
July	1,287.00	1,286.50	6,000	14,000
August	1,286.20	1,286.05	5,850	11,400
September	1,285.90	1,285.80	5,650	10,000
October	1,286.00	1,285.95	5,725	10,700
November	1,286.30	1,286.20	5,850	12,000
December	1,286.30	1,286.30	5,900	12,700
		Mud Lake[2/]		
January	1,285.00	1,285.00	500	700
February	1,285.00	1,285.00	500	700
March	1,286.10	1,286.00	1,500	1,650
April	1,287.50	1,287.30	5,000	5,800
May	1,287.60	1,287.40	5,100	6,300
June	1,287.30	1,287.10	4,750	4,900
July	1,287.00	1,286.50	3,500	3,000
August	1,286.20	1,286.05	1,600	1,700
September	1,285.90	1,285.80	1,200	1,400
October	1,286.00	1,285.95	1,450	1,550
November	1,286.30	1,286.20	2,300	2,000
December	1,286.30	1,286.30	2,800	2,500

Table 21.—Annual operating records of U.S. Fish and Wildlife Service for Sand and Mud Lakes, 1969-81—Continued

Calendar year 1974				
Month	Maximum elevation (feet above sea level)	Average elevation (feet above sea level)	Area (acres)	Capacity (acre-feet)
		Sand Lake[1/]		
January	1,286.30	1,286.30	5,900	12,700
February	1,286.30	1,286.30	5,900	12,700
March	1,287.10	1,286.80	6,100	16,000
April	1,287.50	1,287.40	6,350	19,600
May	1,288.10	1,287.80	6,450	22,000
June	1,288.60	1,288.40	6,700	24,600
July	1,288.60	1,288.50	6,750	25,000
August	1,288.40	1,288.10	6,550	23,400
September	1,287.00	1,286.90	6,150	16,000
October	1,286.80	1,286.80	6,100	16,600
November	1,286.90	1,286.80	6,100	16,000
December	1,286.90	1,286.90	6,150	16,600
		Mud Lake[2/]		
January	1,286.30	1,286.30	2,800	2,300
February	1,286.30	1,286.30	2,800	2,300
March	1,287.50	1,287.30	5,000	5,750
April	1,288.60	1,288.40	6,350	12,600
May	1,289.00	1,288.80	7,000	15,700
June	1,289.20	1,289.10	7,600	17,300
July	1,289.00	1,288.60	6,650	14,300
August	1,288.70	1,288.40	6,350	12,600
September	1,288.15	1,288.10	5,950	10,200
October	1,288.30	1,288.20	6,100	11,000
November	1,288.40	1,288.40	6,350	12,600
December	1,288.40	1,288.40	6,350	12,600

Table 21.--Annual operating records of U.S. Fish and Wildlife Service for Sand and Mud Lakes, 1969-81--Continued

Month	Maximum elevation (feet above sea level)	Average elevation (feet above sea level)	Area (acres)	Capacity (acre-feet)
Calendar year 1975				
Sand Lake[1/]				
January	1,286.90	1,286.90	6,150	16,600
February	1,286.90	1,286.90	6,150	16,600
March	1,286.90	1,286.90	6,150	16,600
April	1,287.90	1,287.60	6,400	20,800
May	1,289.65	1,289.50	[3/] 6,950	[3/] 29,300
June	1,289.74	1,289.40	6,900	[3/] 28,800
July	1,290.88	1,290.50	[3/] 7,250	[3/] 33,200
August	1,289.14	1,288.60	6,700	[3/] 25,400
September	1,288.25	1,287.80	6,450	22,000
October	1,286.90	1,286.80	6,100	16,000
November	1,286.75	1,286.60	6,050	14,400
December	1,286.20	1,285.70	5,550	9,400
Mud Lake[2/]				
January	1,288.40	1,288.40	6,350	12,600
February	1,288.40	1,288.40	6,350	12,600
March	1,288.40	1,288.40	6,350	12,600
April	1,288.60	1,288.50	6,500	13,500
May	1,290.15	1,290.00	[3/] 9,000	[3/] 20,500
June	1,289.74	1,289.70	[3/] 8,600	[3/] 19,200
July	1,291.45	1,291.00	[3/] 10,000	[3/] 23,000
August	1,289.12	1,289.00	7,400	16,850
September	1,288.46	1,288.30	6,200	11,900
October	1,288.42	1,288.35	6,275	12,200
November	1,288.20	1,288.00	5,800	9,500
December	1,286.50	1,286.40	3,250	2,600

Table 21.--Annual operating records of U.S. Fish and Wildlife Service for Sand and Mud Lakes, 1969-81—Continued

Month	Maximum elevation (feet above sea level)	Average elevation (feet above sea level)	Area (acres)	Capacity (acre-feet)
Calendar year 1976				
Sand Lake[1/]				
January	1,285.70	1,285.70	5,550	9,400
February	1,285.70	1,285.70	5,550	9,400
March	1,287.30	1,286.90	6,150	16,600
April	1,288.80	1,288.20	6,575	23,900
May	1,288.75	1,288.50	6,650	[3/] 25,000
June	1,287.11	1,286.80	6,100	16,000
July	1,286.30	1,285.80	5,600	10,000
August	1,285.17	1,285.00	3,350	6,400
September	1,284.77	1,284.50	2,500	4,600
October	1,284.10	1,284.00	2,050	3,200
November	1,283.74	1,283.60	1,800	2,400
December	1,283.60	1,283.60	1,800	2,400
Mud Lake[2/]				
January	1,286.40	1,286.40	3,250	2,600
February	1,286.40	1,286.40	3,250	2,600
March	1,287.99	1,287.60	5,350	7,150
April	1,288.80	1,288.60	6,650	14,300
May	1,288.79	1,288.30	6,200	11,900
June	1,288.04	1,287.80	5,550	8,250
July	1,287.80	1,287.20	4,875	5,300
August	1,286.60	1,286.30	2,800	2,300
September	1,285.81	1,285.60	950	1,150
October	1,284.60	1,284.40	275	450
November	1,283.70	1,283.70	175	250
December	1,283.40	1,283.40	150	200

Table 21.—Annual operating records of U.S. Fish and Wildlife Service for Sand and Mud Lakes, 1969-81--Continued

Calendar year 1977					
Month	Maximum elevation (feet above sea level)	Minimum elevation (feet above sea level)	Average elevation (feet above sea level)	Area (acres)	Capacity (acre-feet)
Sand Lake[1/]					
January	1,283.60	1,283.60	1,283.60	1,850	2,520
February	1,283.60	1,283.60	1,283.60	1,850	2,520
March	1,285.00	1,284.48	1,284.74	3,358	5,459
April	1,284.94	1,284.75	1,284.84	3,582	5,811
May	1,284.16	1,283.74	1,283.95	2,119	3,224
June	1,284.06	1,282.90	1,283.48	1,758	2,279
July	1,282.60	--	1,282.60	1,269	961
August	1,284.10	--	1,284.10	2,234	3,526
September	1,284.20	1,284.17	1,284.18	2,295	3,687
October	1,284.45	--	1,284.40	2,597	4,264
November	1,285.70	1,284.45	1,285.08	4,120	6,655
December	1,285.70	1,285.70	1,285.70	5,153	9,530
Mud Lake[2/]					
January	1,283.40	1,283.40	1,283.40	144	195
February	1,283.40	1,283.40	1,283.40	144	195
March	1,287.17	1,286.35	1,286.76	3,124	3,376
April	1,288.35	1,287.90	1,288.12	5,708	9,511
May	1,288.10	1,287.90	1,288.00	5,570	8,869
June	1,288.10	1,287.58	1,287.84	5,385	8,063
July	1,287.54	[3/] 1,286.53	1,287.04	3,964	4,293
August	1,286.33	[3/] 1,285.75	1,286.04	1,438	1,588
September	1,286.25	1,285.95	1,286.10	1,511	1,658
October	1,287.08	[3/] 1,287.00	1,287.04	3,964	4,293
November	[3/] 1,287.08	[3/] 1,287.00	1,287.04	3,964	4,293
December	[3/] 1,287.00	[3/] 1,287.00	1,287.00	3,844	4,162

Table 21.—Annual operating records of U.S. Fish and Wildlife Service for Sand and Mud Lakes, 1969-81—Continued

Calendar year 1978					
Month	Maximum elevation (feet above sea level)	Minimum elevation (feet above sea level)	Average elevation (feet above sea level)	Area (acres)	Capacity (acre-feet)
Sand Lake[1/]					
January	1,285.70	1,285.70	1,285.70	5,153	9,530
February	1,285.70	1,285.70	1,285.70	5,153	9,530
March	1,285.5	1,285.0	1,286.25	5,884	[3/] 12,444
April	1,290.15	1,288.75	1,289.45	7,000	[3/] 33,000
May	1,288.40	1,287.62	1,288.01	6,494	23,363
June	1,288.16	1,287.78	1,287.97	6,480	23,106
July	1,288.36	1,287.52	1,287.94	6,469	22,913
August	1,287.91	1,287.67	1,287.79	6,416	21,950
September	1,288.2	1,287.5	1,287.85	6,438	22,335
October	1,287.42	1,287.39	1,287.40	6,279	19,445
November	1,287.35	1,287.00	1,287.18	6,210	18,073
December	1,286.78	1,286.78	1,286.78	6,097	15,631
Mud Lake[2/]					
January	[3/] 1,287.00	[3/] 1,287.00	1,287.00	3,844	4,162
February	[3/] 1,287.00	[3/] 1,287.00	1,287.00	3,844	4,162
March	1,288.10	1,286.42	1,287.26	[3/] 4,624	[3/] 5,013
April	1,290.25	1,288.44	1,289.34	[3/] 7,700	[3/] 17,500
May	1,288.98	1,288.16	1,288.57	6,382	12,297
June	1,289.16	1,288.7	1,288.93	7,013	14,745
July	1,289.11	1,288.56	1,288.84	6,855	14,133
August	1,288.72	1,288.55	1,288.64	6,505	12,773
September	1,288.56	1,288.12	1,288.34	5,980	10,732
October	1,288.7	1,287.75	1,288.22	5,820	10,046
November	[3/] 1,287.33	[3/] 1,287.33	1,287.33	4,797	5,284
December	[3/] 1,287.10	[3/] 1,287.10	1,287.10	4,144	4,489

Table 21.--Annual operating records of U.S. Fish and Wildlife Service for Sand and Mud Lakes, 1969-81--Continued

Calendar year 1979

Month	Maximum elevation (feet above sea level)	Minimum elevation (feet above sea level)	Average elevation (feet above sea level)	Area (acres)	Capacity (acre-feet)
Sand Lake[1/]					
January	1,286.78	1,286.78	1,286.78	6,100	15,700
February	1,286.78	1,286.78	1,286.78	6,100	15,700
March	1,286.95	1,286.78	1,286.87	6,150	[3/]16,300
April	1,291.50	1,286.82	1,289.16	[3/]6,850	[3/]27,800
May	1,291.48	1,289.38	1,290.43	[3/]7,250	[3/]33,000
June	1,288.90	1,288.28	1,288.59	6,700	[3/]25,600
July	1,288.38	1,288.04	1,288.21	6,575	23,900
August	1,288.04	1,287.64	1,287.84	6,475	22,100
September	1,287.80	1,287.60	1,287.70	6,425	21,400
October	1,287.58	1,287.56	1,287.57	6,400	20,600
November	1,287.25	1,287.12	1,287.19	6,250	18,400
December	1,286.95	1,286.56	1,286.76	6,100	15,600
Mud Lake[2/]					
January	1,287.33	1,287.33	1,287.33	4,900	5,900
February	1,287.33	1,287.33	1,287.33	4,900	5,900
March	1,288.30	1,287.33	1,287.82	[3/]5,600	[3/]8,300
April	1,291.53	1,288.10	1,289.82	[3/]8,800	[3/]19,500
May	1,291.24	1,289.94	1,290.59	[3/]9,500	[3/]21,400
June	1,289.60	1,288.90	1,289.25	[3/]7,850	[3/]17,750
July	1,288.96	1,288.78	1,288.87	7,125	16,100
August	1,288.88	1,288.38	1,288.63	6,700	14,500
September	1,288.60	1,288.40	1,288.50	6,475	13,500
October	1,288.80	1,288.78	1,288.79	7,000	15,650
November	1,288.70	1,288.52	1,288.61	6,675	14,400
December	1,287.92	1,287.83	1,287.88	5,650	8,700

Table 21.—Annual operating records of U.S. Fish and Wildlife Service for Sand and Mud Lakes, 1969-81—Continued

Calendar year 1980					
Month	Maximum elevation (feet above sea level)	Minimum elevation (feet above sea level)	Average elevation (feet above sea level)	Area (acres)	Capacity (acre-feet)
			Sand Lake[1/]		
January	1,286.76	1,286.76	1,286.76	6,100	15,600
February	1,286.85	1,286.85	1,286.85	6,150	16,300
March	1,287.30	1,287.00	1,287.15	6,250	18,200
April	1,288.10	1,287.78	1,287.94	6,500	22,700
May	1,287.92	1,287.72	1,287.82	6,475	22,000
June	1,287.90	1,287.65	1,287.78	6,450	21,800
July	1,287.48	1,287.00	1,287.24	6,275	18,800
August	1,286.94	1,286.80	1,286.87	6,150	16,300
September	1,286.80	1,286.74	1,286.77	6,100	15,600
October	1,286.81	1,286.66	1,286.74	6,100	15,600
November	1,286.86	1,286.75	1,286.81	6,125	15,900
December	1,286.80	1,286.80	1,286.80	6,125	15,900
			Mud Lake[2/]		
January	1,288.50	1,288.50	1,288.50	6,500	13,500
February	1,288.33	1,288.33	1,288.33	6,250	12,000
March	1,288.72	1,288.24	1,288.48	6,450	13,200
April	1,288.94	1,288.60	1,288.77	6,900	15,400
May	1,288.52	1,288.42	1,288.47	6,450	13,200
June	1,288.40	1,288.35	1,288.38	6,300	12,500
July	1,288.25	1,288.08	1,288.17	6,025	10,750
August	1,287.60	1,287.60	1,287.60	5,325	7,150
September	1,287.70	1,287.40	1,287.55	5,275	6,900
October	1,288.26	1,288.08	1,288.17	6,025	10,750
November	1,288.23	1,288.22	1,288.23	6,125	11,300
December	1,288.00	1,287.70	1,287.85	5,625	8,500

Table 21.—Annual operating records of U.S. Fish and Wildlife Service for Sand and Mud Lakes, 1969-81—Continued

Calendar year 1981					
Month	Maximum elevation (feet above sea level)	Minimum elevation (feet above sea level)	Average elevation (feet above sea level)	Area (acres)	Capacity (acre-feet)
Sand Lake1/					
January	1,286.80	1,286.80	1,286.80	6,125	15,900
February	1,286.80	1,286.80	1,286.80	6,125	15,900
March	1,287.38	1,287.09	1,287.24	6,300	18,800
April	1,287.60	1,287.50	1,287.55	6,400	20,600
May	1,287.38	1,287.10	1,287.24	6,300	18,800
June	1,287.40	1,287.28	1,287.34	6,325	19,300
July	1,287.38	1,287.28	1,287.33	6,325	19,300
August	1,287.40	1,286.90	1,287.15	6,250	18,200
September	1,287.02	1,286.78	1,286.90	6,150	16,600
October	1,286.90	1,286.82	1,286.86	6,125	16,300
November	1,287.05	1,286.74	1,286.90	6,150	16,600
December	1,287.05	1,286.80	1,286.93	6,175	16,700
Mud Lake2/					
January	1,287.83	1,287.83	1,287.83	5,600	8,400
February	1,287.83	1,287.83	1,287.83	5,600	8,400
March	1,288.64	1,288.35	1,288.50	6,500	13,500
April	1,288.52	1,288.34	1,288.43	6,400	13,000
May	1,288.32	1,288.28	1,288.30	6,200	11,900
June	1,288.46	1,288.32	1,288.39	6,300	12,600
July	1,288.54	1,288.40	1,288.47	6,450	13,200
August	1,288.24	1,288.00	1,288.12	6,000	10,400
September	1,288.36	1,287.90	1,288.13	6,000	10,400
October	1,288.44	1,288.40	1,288.42	6,400	12,900
November	1,288.40	1,288.28	1,288.34	6,250	12,300
December	1,288.32	1,287.50	1,287.91	5,700	8,900

1/ Elevation of spillway crest, 1,287.52 feet.
2/ Elevation of spillway crest, 1,288.23 feet.
3/ Estimated.

Monthly content and surface area of Sand and Mud Lakes

Table 22.—Monthly content of Sand Lake, in acre-feet, during 1969-81 (based on U.S. Bureau of Reclamation area-capacity curve dated May 14, 1981)

YEAR	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
1969	4500	4500	4500	24500	37000	24000	20000	16500	20300	22300	19700	11000
1970	4000	2800	2800	9750	9750	3000	2000	1000	610	610	610	610
1971	610	610	610	9925	18700	22300	23200	14000	9750	11000	6500	6500
1972	6500	6500	20750	15205	11500	16250	16250	14000	9925	10500	7750	5050
1973	5810	5810	6000	17000	18700	15500	12500	9925	9000	9750	11000	11500
1974	11500	11500	14000	18700	20000	23750	24500	22000	15000	14000	14000	15000
1975	15000	15000	15000	19000	31500	30500	36250	25000	20000	14000	13000	8750
1976	8750	8750	15000	22300	24500	14000	9000	5810	4500	3285	2500	2500
1977	2500	2500	5300	5500	3285	2500	1250	3500	3750	4250	6300	6750
1978	8750	8750	11500	31000	21210	21210	22000	20000	20500	17500	16500	14000
1979	14000	14000	14500	23500	36200	25000	22500	20000	19500	18500	16250	13700
1980	13700	14500	16200	22000	20000	19750	16500	14500	14000	14000	14200	14200
1981	14200	14200	17100	18500	15500	17000	17000	15900	15000	14000	15000	15000

Table 23.—Monthly surface area of Sand Lake, in acres, during 1969-81 (based on U.S. Bureau of Reclamation area-capacity curve dated May 14, 1981)

YEAR	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
1969	2700	2700	2700	6450	7200	6400	6180	6100	6200	6350	6150	5050
1970	2400	1750	1750	4700	4700	1800	1400	950	780	780	780	780
1971	780	780	780	4810	6100	6350	6370	5550	4700	5050	3500	3500
1972	3500	3500	6250	5750	5200	5900	5900	5600	4810	4950	4000	3000
1973	3220	3220	4200	5900	6100	5800	5400	4810	4500	4700	5050	5200
1974	5200	5200	5600	6100	6180	6400	6450	6300	5700	5600	5600	5700
1975	5700	5700	5700	6100	6850	6800	7600	6500	6180	5600	5450	4400
1976	4400	4400	5700	6350	6450	5600	4500	3220	2700	2050	1700	1700
1977	1700	1700	2950	3000	2050	1650	1100	2200	2300	2500	3400	4400
1978	4400	4400	5200	6825	6260	6260	6280	6170	6200	6000	5860	5560
1979	5560	5560	5650	6670	7240	6450	6340	6200	6150	6060	5840	5550
1980	5550	5650	5800	6260	6200	6150	5900	5680	5550	5500	5600	5600
1981	5600	5600	5950	6100	5800	5900	5900	5850	5700	5600	5700	5700

Table 24.—Monthly content of Mud Lake, in acre-feet, during 1969-81 (based on U.S. Bureau of Reclamation area-capacity curve dated May 14, 1981)

YEAR	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
1969	590	590	590	25000	29000	6600	6045	5100	5100	4900	4700	1100
1970	1000	1000	1000	11100	5300	4000	5100	3200	1650	1100	1300	1100
1971	700	700	2800	9800	6000	6000	5100	1700	1100	3200	5300	800
1972	590	590	14200	6600	4700	3600	2900	6800	4300	400	300	250
1973	100	100	590	3200	3600	2600	1300	600	400	560	800	1000
1974	1000	1000	3200	6000	10800	12600	9200	6000	6400	7000	6000	6000
1975	6000	6000	6000	6600	20235	17600	23000	12000	6700	7700	6045	1100
1976	1100	1100	4300	9200	6700	5100	2800	1000	300	50	0	0
1977	0	0	1900	6400	6045	5100	2360	590	700	2360	2360	2360
1978	2360	2360	3100	14800	9000	11400	12000	10000	7800	7000	3300	2600
1979	3330	3330	5200	16800	21400	13900	11600	9400	6600	10400	9300	5500
1980	6600	7600	6600	10400	8600	6000	6900	4250	4100	6900	7000	5400
1981	5400	5400	9300	6600	6700	6600	6600	6400	6400	6600	7600	5600

Table 25.—Monthly surface area of Mud Lake, in acres, during 1969-81 (based on U.S. Bureau of Reclamation area-capacity curve dated May 14, 1981)

YEAR	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
1969	820	820	820	6300	6700	5800	4650	4200	4200	4150	4050	1500
1970	1400	1400	1400	6800	4350	3700	4200	3250	2125	1600	1750	1600
1971	1000	1000	3000	6250	5550	5550	4200	2100	1550	3250	4400	1100
1972	820	820	7750	5800	4050	3450	3100	5000	3900	600	450	300
1973	160	160	820	3250	3450	2900	1750	830	600	800	1200	1400
1974	1400	1400	3250	5550	6500	7250	6000	5550	4900	5100	5550	5550
1975	5550	5550	5550	5800	9540	8800	10000	7000	5300	5450	4650	1600
1976	1600	1600	3900	6000	5300	4200	3000	1400	450	100	0	0
1977	0	0	2350	4900	4650	4200	2720	820	1000	2720	2720	2720
1978	2720	2720	3150	7850	5900	6830	6600	6300	5500	5170	3300	2900
1979	3400	3400	4320	9200	9500	7600	6900	6100	5800	6500	6070	4400
1980	5800	5370	5800	6450	5800	5500	5050	3860	3730	5050	5200	4400
1981	4400	4400	6070	5800	5300	5800	5800	4900	4900	5800	5370	4400

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